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Speicherung regenerativer elektrischer Energien und die Vektorisierung von regenerativem Wasserstoff

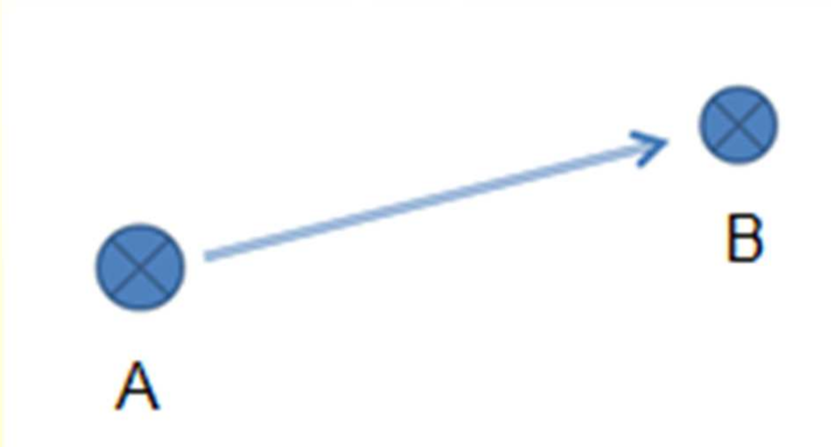
Jürgen Garche

www.fcbat.eu

Inhalt

- Regenerative Energien im Netz
- Speicherung Regenerativer Energien
  - Elektrisch
  - Wasserstoff
  - Power-to-Gas
  - Chemisch
- Zusammenfassung

Vectorisierung

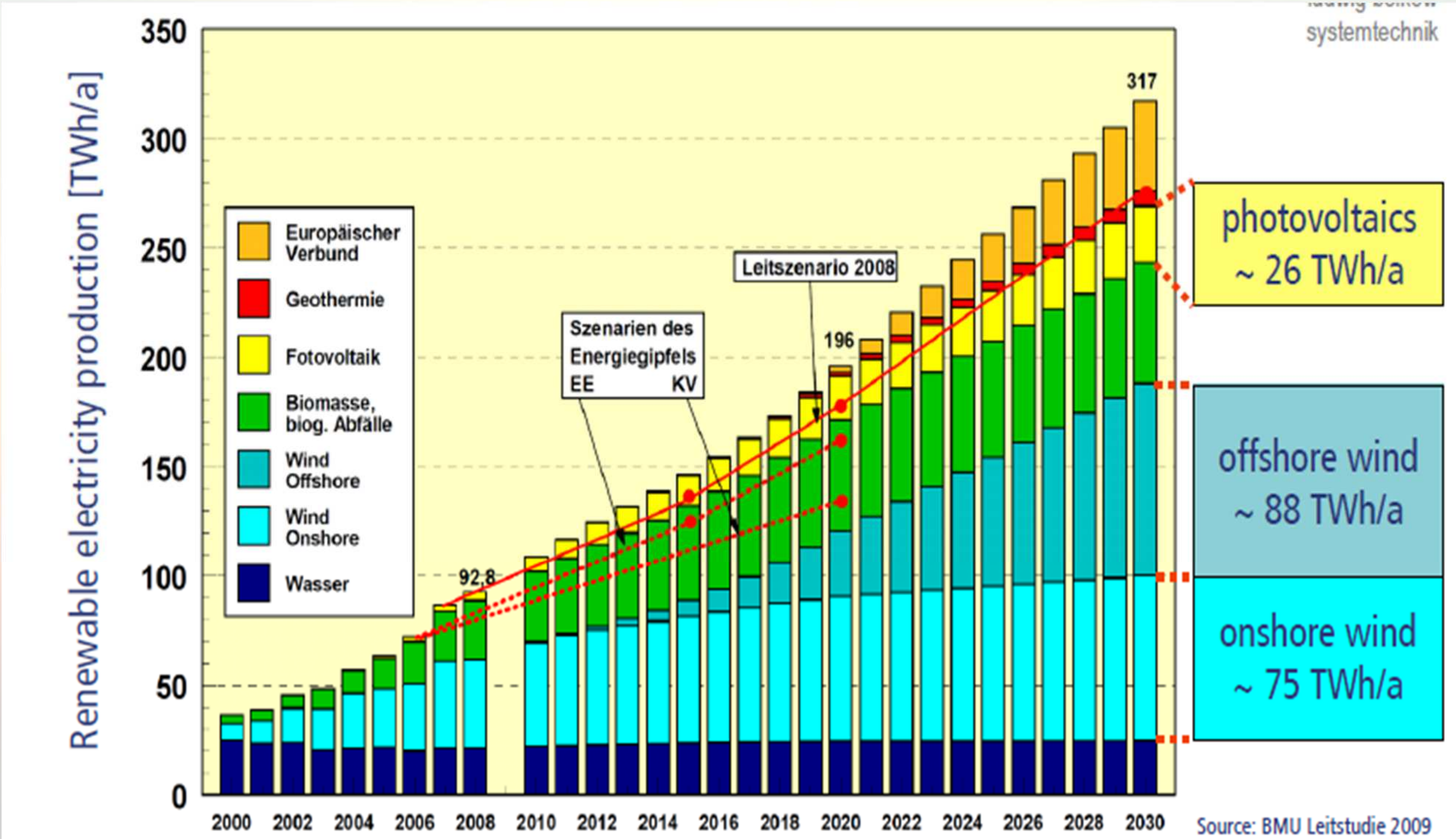


Ortsverschiebung (Transport) von A nach B.

Fragen: - Transportverluste

- Transportform
- Transportbehälter

Wieviel Regenerative?



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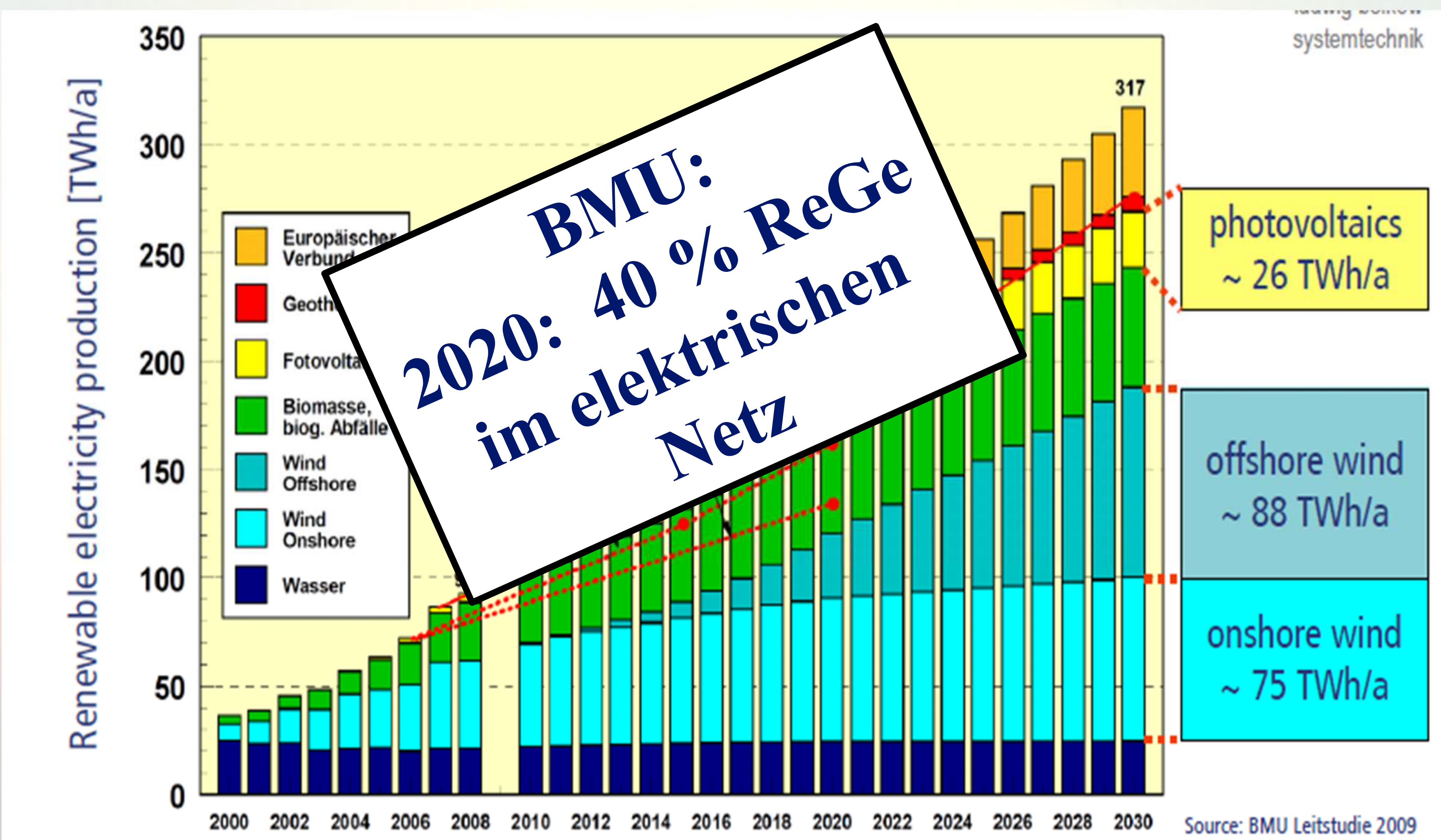
Wieviel Regenerative?



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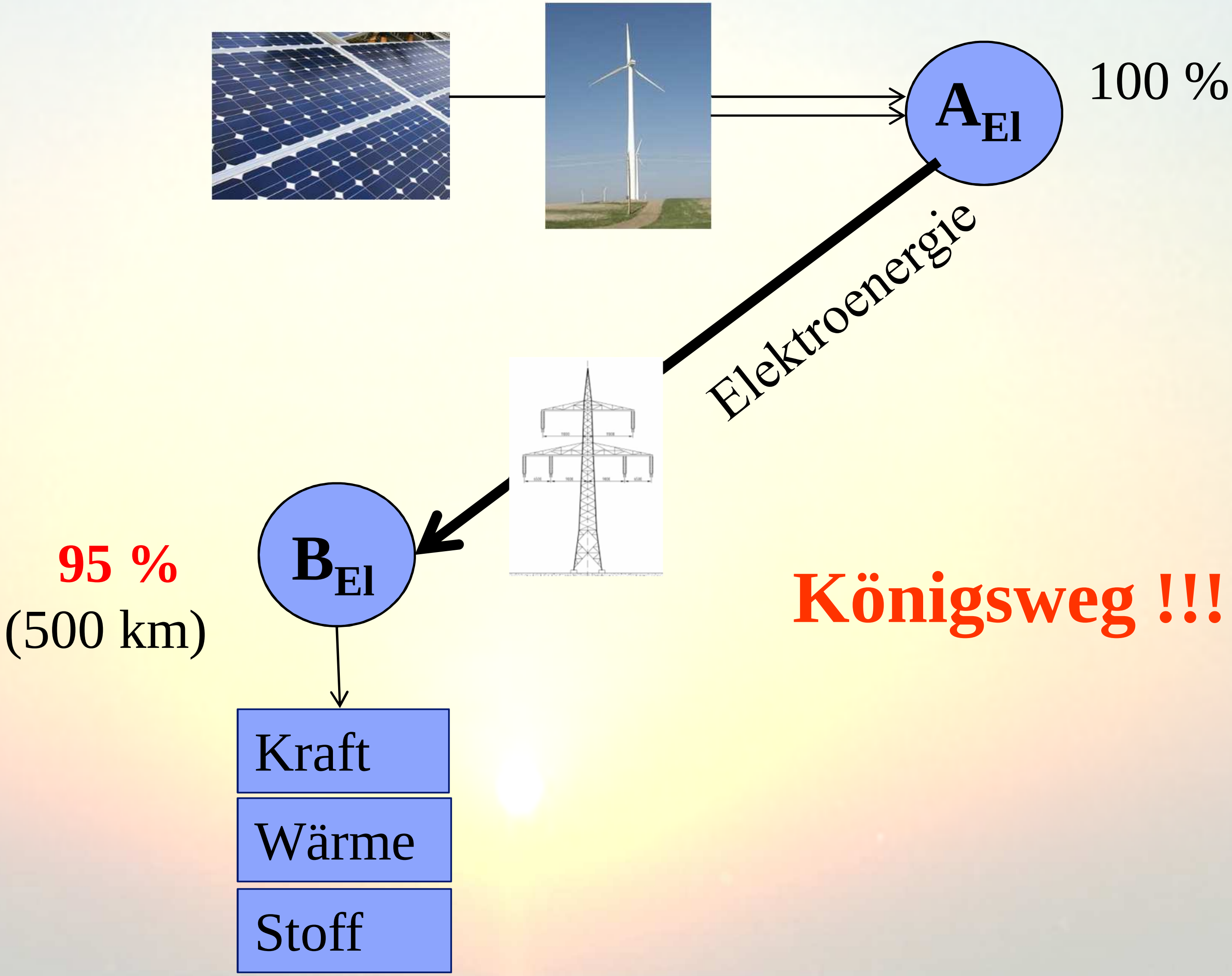
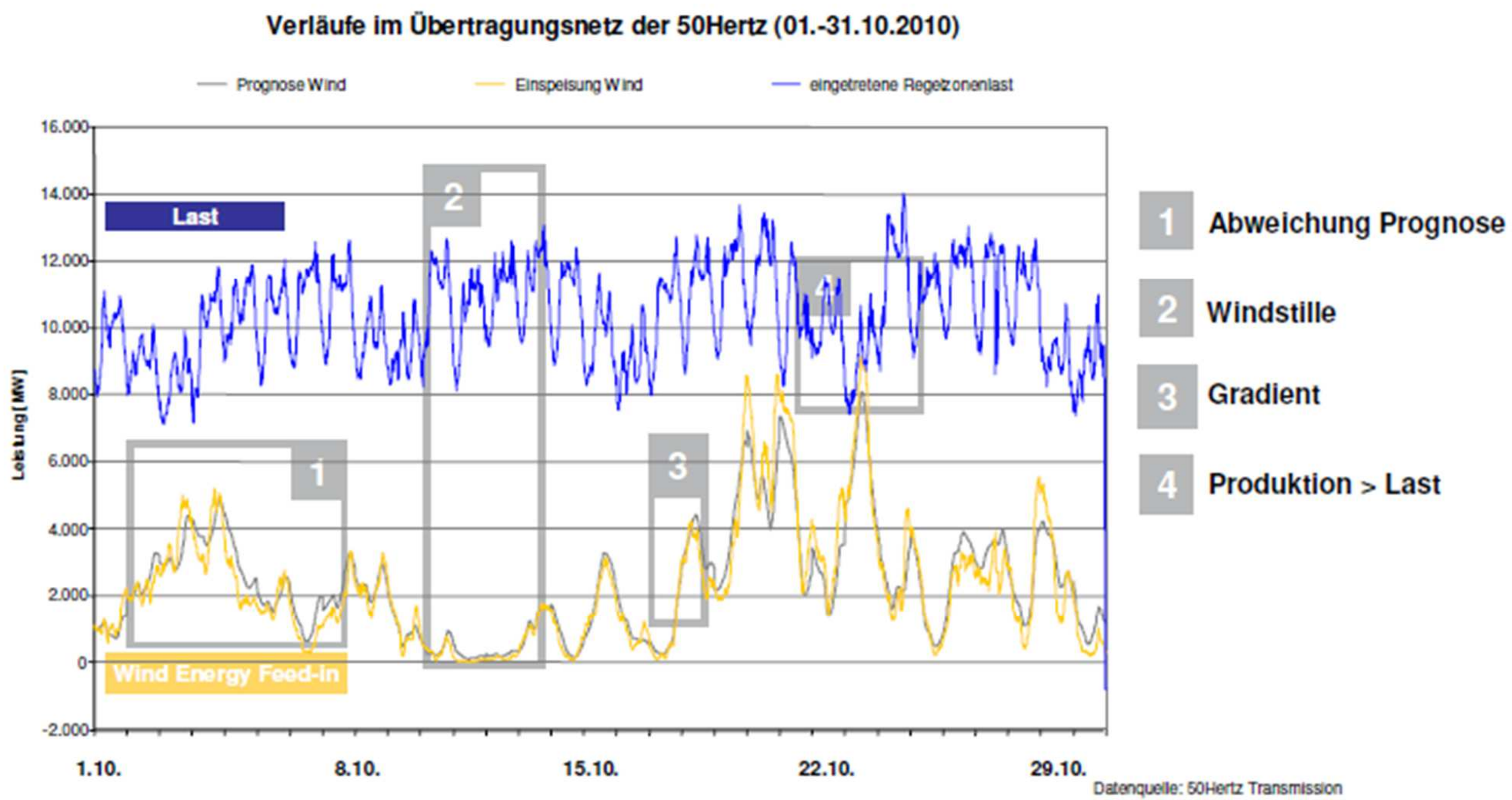


A_{El}
100 %
Elektroenergie
B_{El}
95 %
(500 km)
Kraft
Wärme
Stoff
Königsweg !!!

Netzlast, Windenergieprognose und Windenergieeinspeisung in Ost-Deutschland (01-31.10.2010)



VATTENFALL

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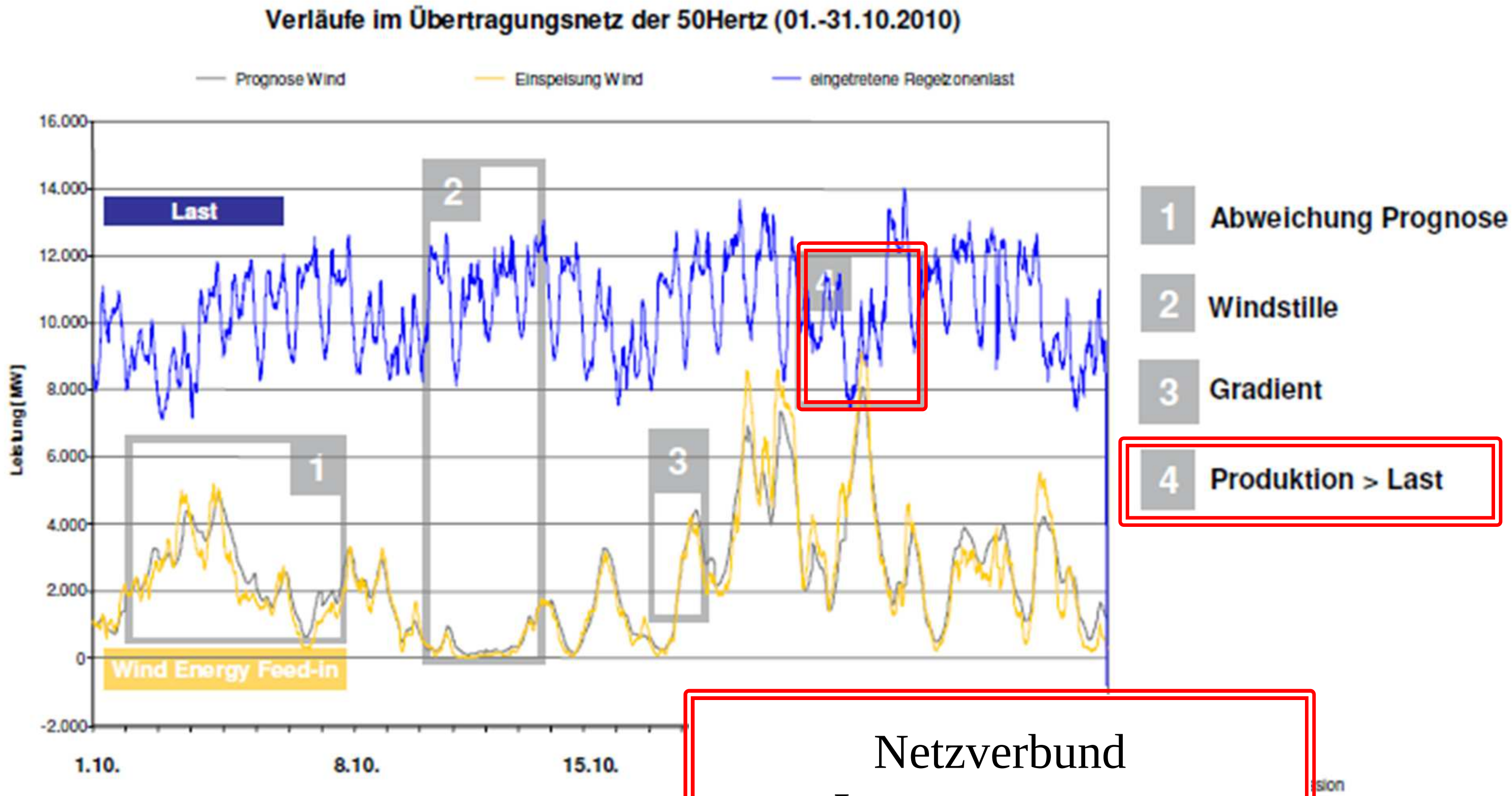
Netzlast, Windenergieprognose und Windenergieeinspeisung in Ost-Deutschland (01-31.10.2010)



Netzverbund
Lastmanagement
Energiespeicherung (Ladung)

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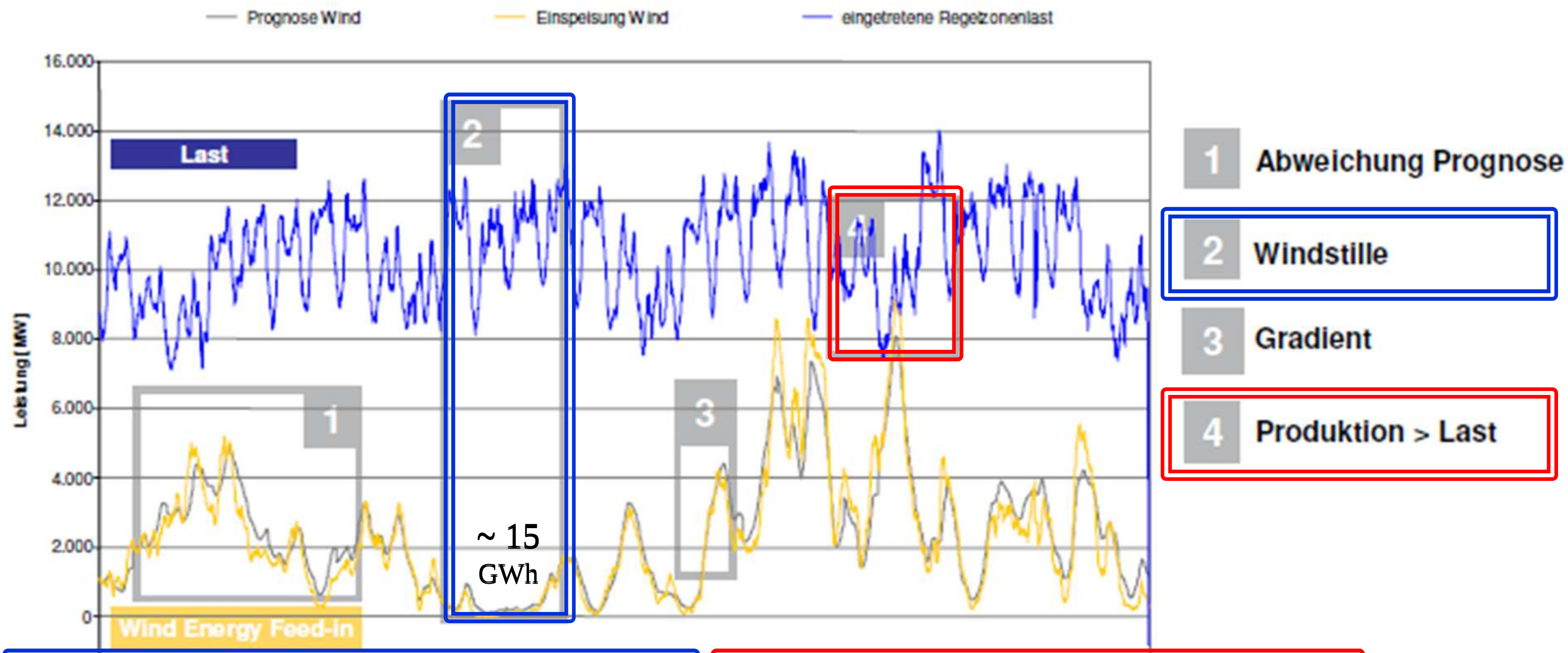
Netzlast, Windenergieprognose und Windenergieeinspeisung in Ost-Deutschland (01-31.10.2010)

Verläufe im Übertragungsnetz der 50Hertz (01.-31.10.2010)



Regel/Reservekraftwerke
Netzverbund
Lastmanagement
Energiespeicherung **(Entlad.)**

Netzverbund
Lastmanagement
Energiespeicherung **(Ladung)**

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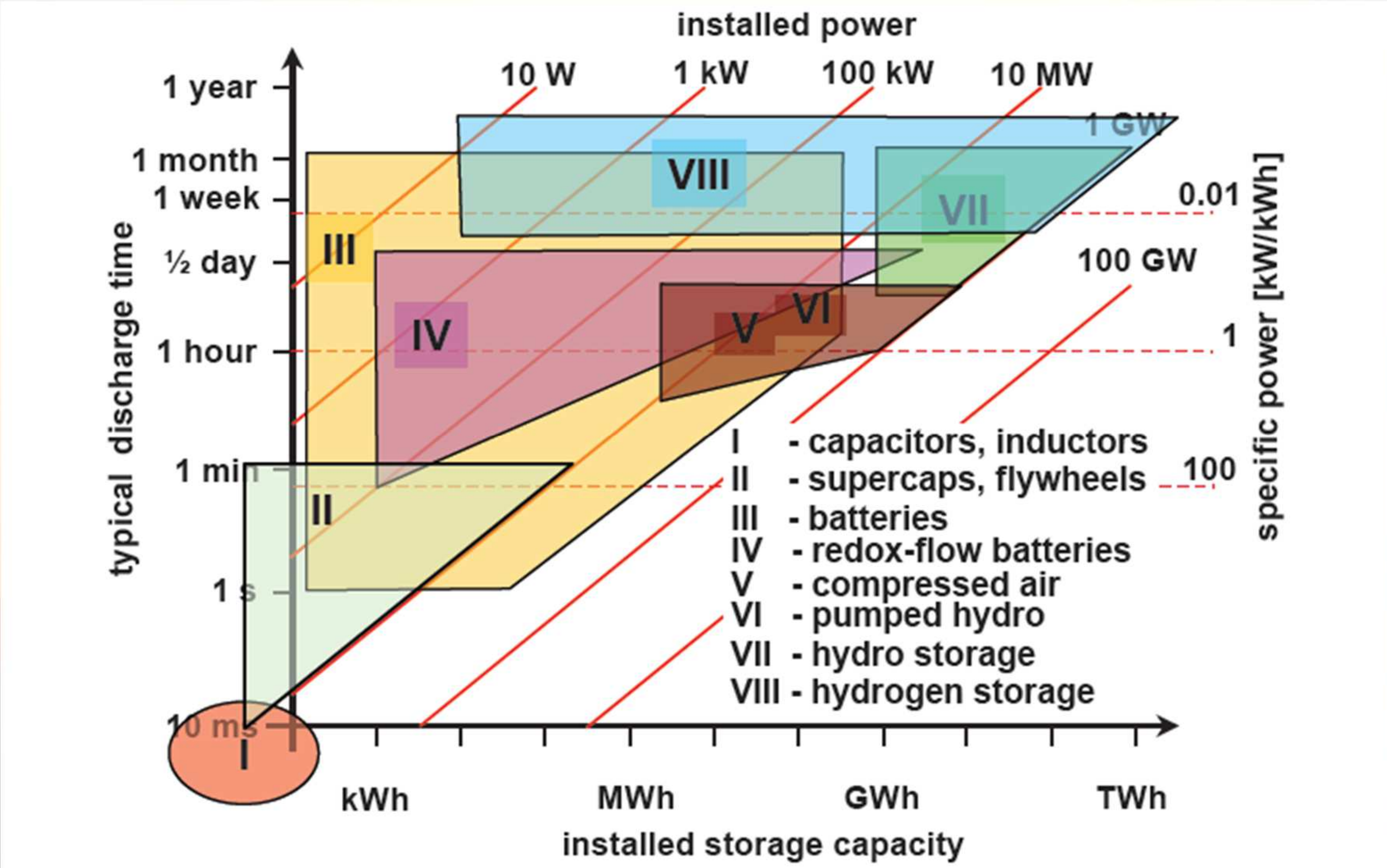
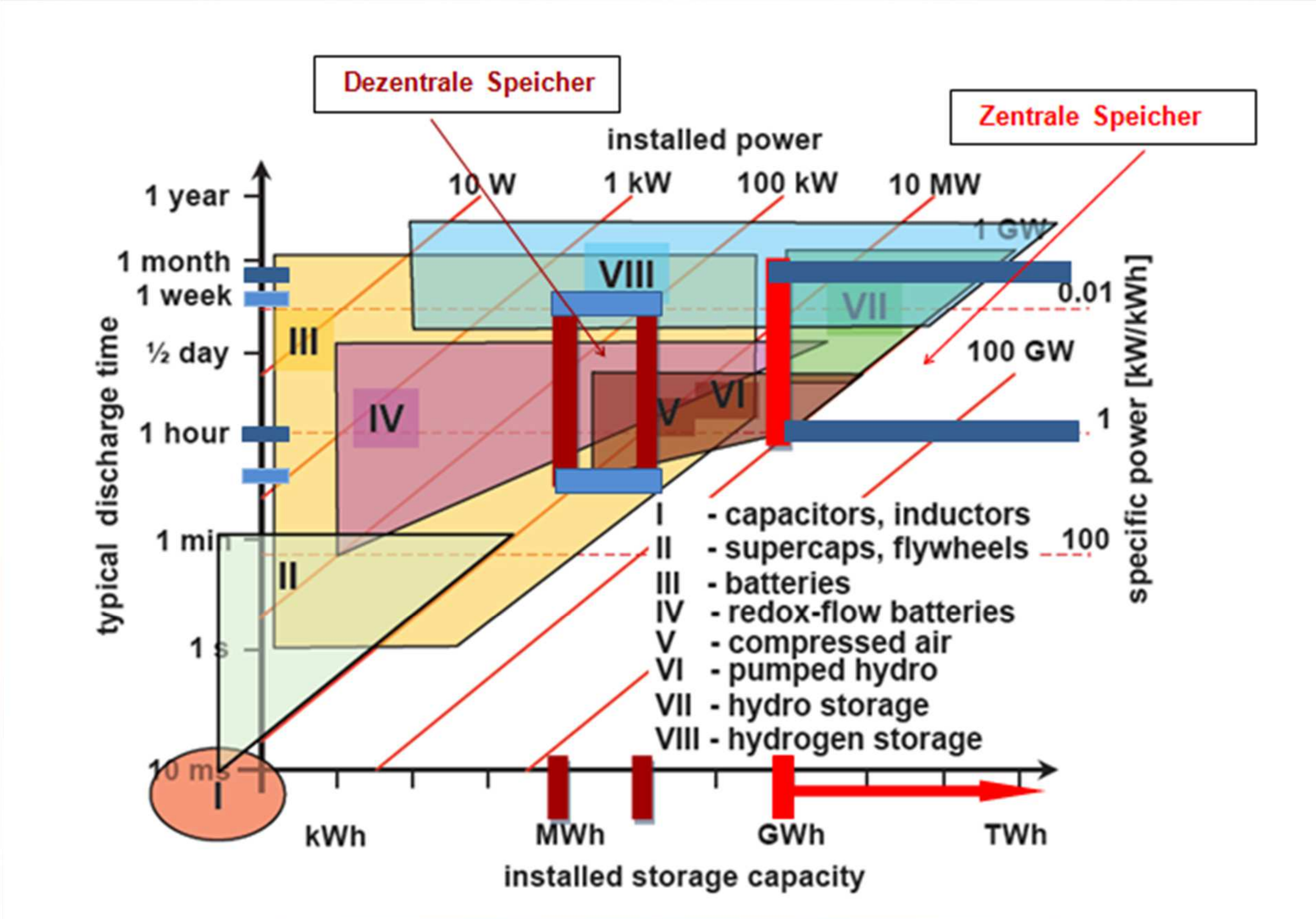
Energiespeicherung




Dezentrale Speicher
Zentrale Speicher
installed power
10 W
1 kW
100 kW
10 MW
1 GW
100 GW
1 year
1 month
1 week
½ day
1 hour
1 min
1 s
10 ms
typical discharge time
III
IV
VIII
V
VI
VII
II
I
0.01
1
100
specific power [kW/kWh]
I - capacitors, inductors
II - supercaps, flywheels
III - batteries
IV - redox-flow batteries
V - compressed air
VI - pumped hydro
VII - hydro storage
VIII - hydrogen storage
kWh
MWh
GWh
TWh
installed storage capacity

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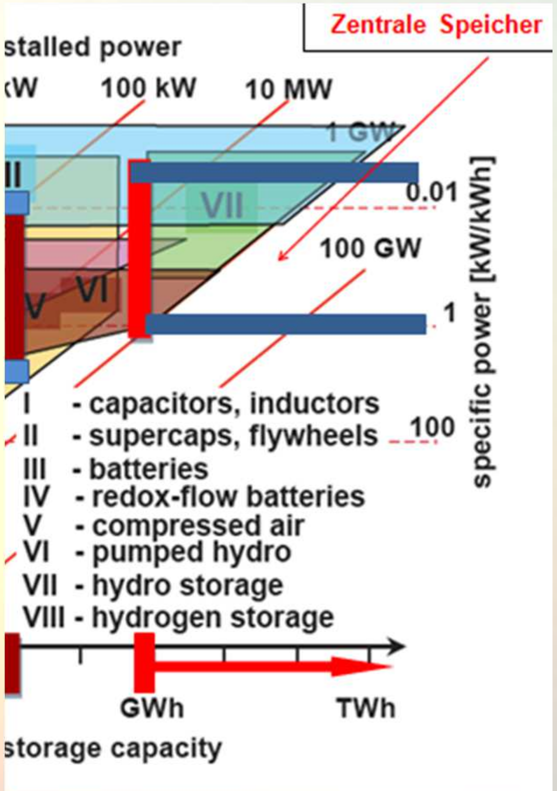
Zentrale Speicher

GWh-Bereich, Speicherzeit 1 h - 2 Wochen,
Entladeleistungen 10 MW - 1 GW

- Pumpspeicherkraftwerke (VI)
- Druckluft-Speichersysteme - CAES (V)
- DruckH2-Speichersysteme - CHES (VIII)



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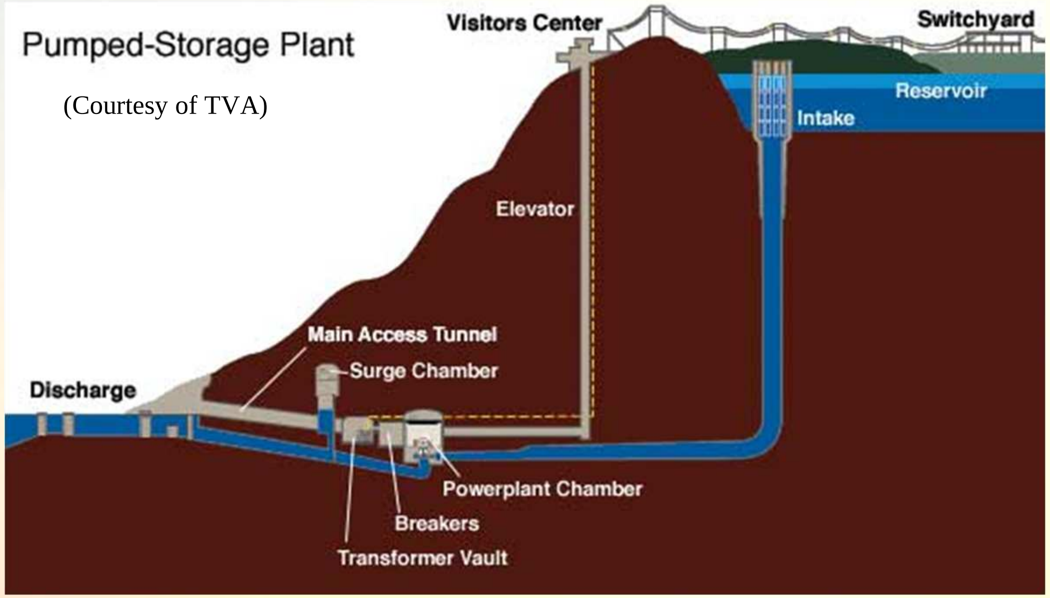
Pumpspeicherkraftwerke



Limitiertes Wachstmspotential in Deutschland

η **> 80 %**

Ort	Name	Inbetrieb-nahme	Höhendiff-erenz [m]	Max. Leist-ung [MW]	Entlade-dauer [h]	Anlagekost-en [Mio €]
Deutschland	Schluchsee	1932	620	512	314	
Österreich	Lünersee	1958	974	231	788	
Wales/GB	Dinorwig	1984	545	1890	5	310
USA / CA	Helms	1984	520	1212	153	416
USA / VA	Bath County	1985	380	2700	11	1650
Japan	Kazunogowa	2001	714	1600	8,2	3200
Deutschland	Goldisthal	2002	302	1060	8	700

Voraussetzung:

- Topographische Lagen,

- Bürgerakzeptanz

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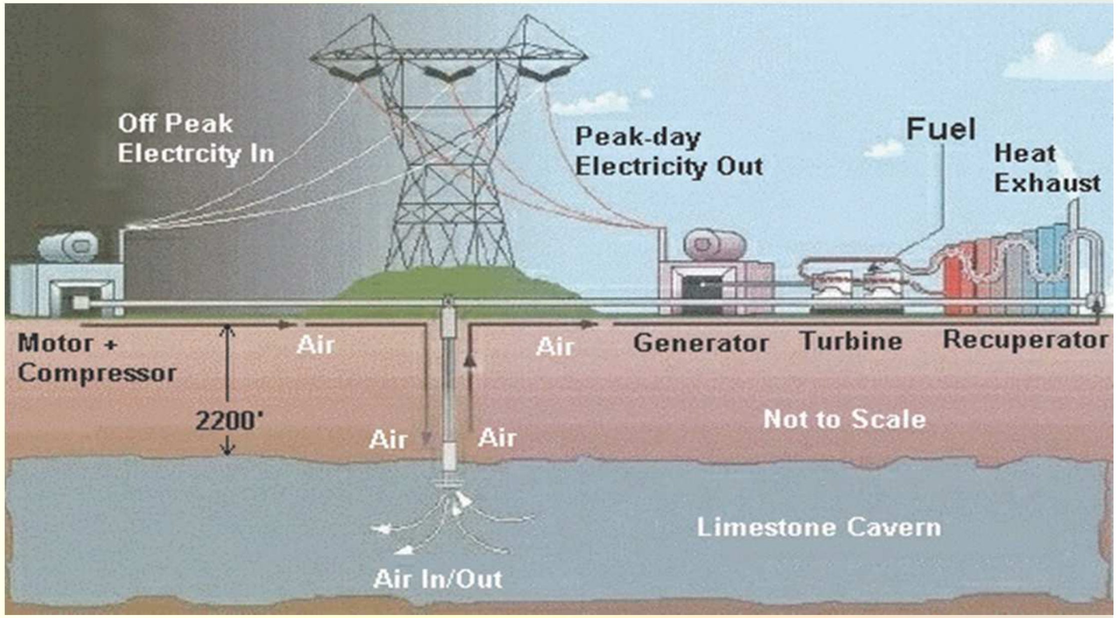
Compressed Air Energy Storage (CAES)



Location	Huntorf, Germany	McIntosh, USA
Commissioned	1978	1991
Store	Two cylindrical salt caverns, each with 150,000 m³ at a depth of 600 m – 800 m (height 200 m, diameter: 30 m)	Salt cavern, 538,000 m³ at a depth of 450 m – 750 m
Output	290 MW over 2 hours	110 MW over 26 hours
Energy required for 1 kWh el	0.8 kWh electricity	0.69 kWh electricity
	1.6 kWh gas	1.17 kWh gas
Pressure tolerance	50 – 70 bar	45 – 76 bar
Remark	World's first CAES plant	First CAES plant with recuperator

$\eta \approx 50\ \%$

ACAES ≈ 70 %

Voraussetzung:

Salzkavernen

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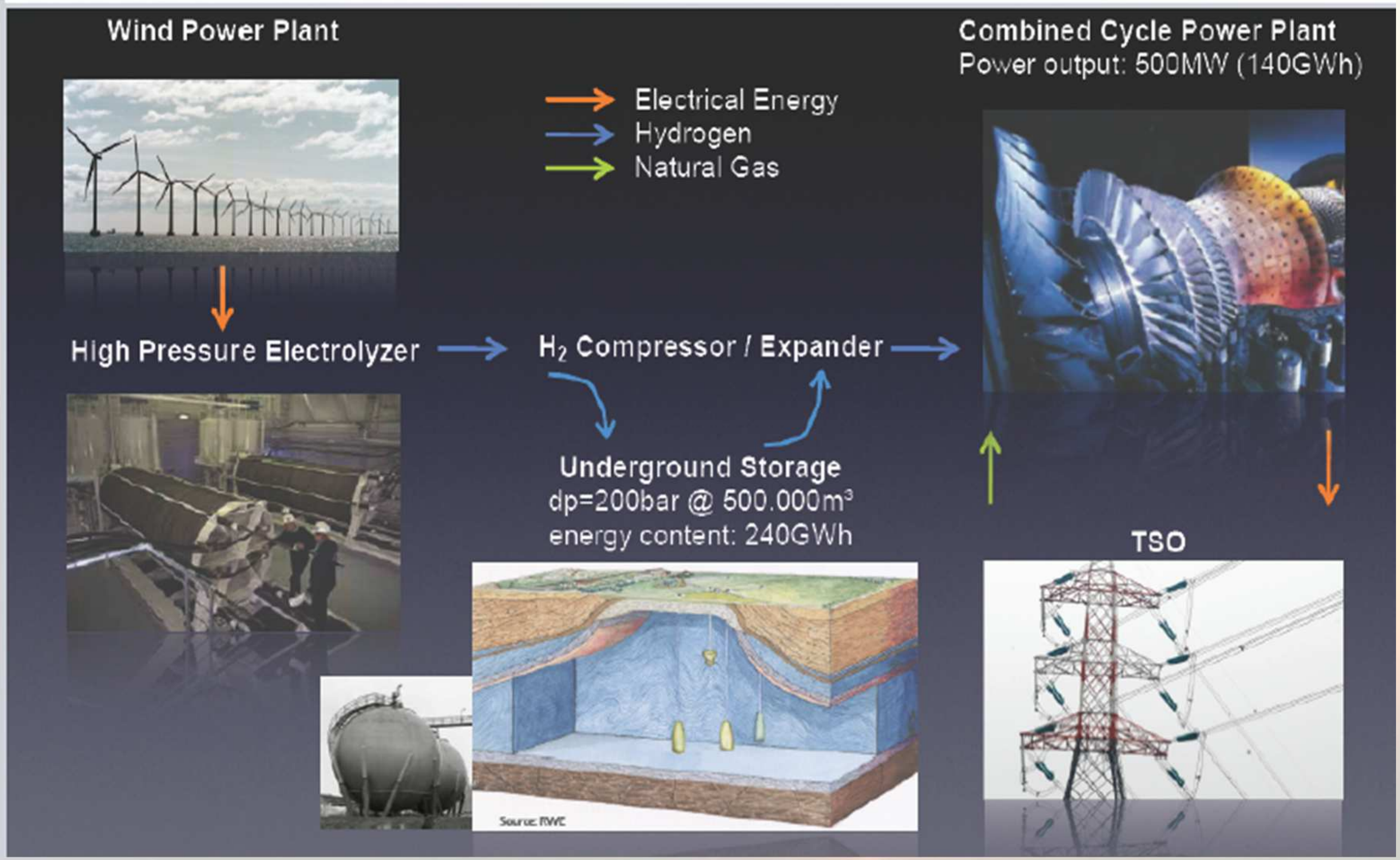
BINE-Project Info 05/07

Compressed Hydrogen Energy Storage (CHES)

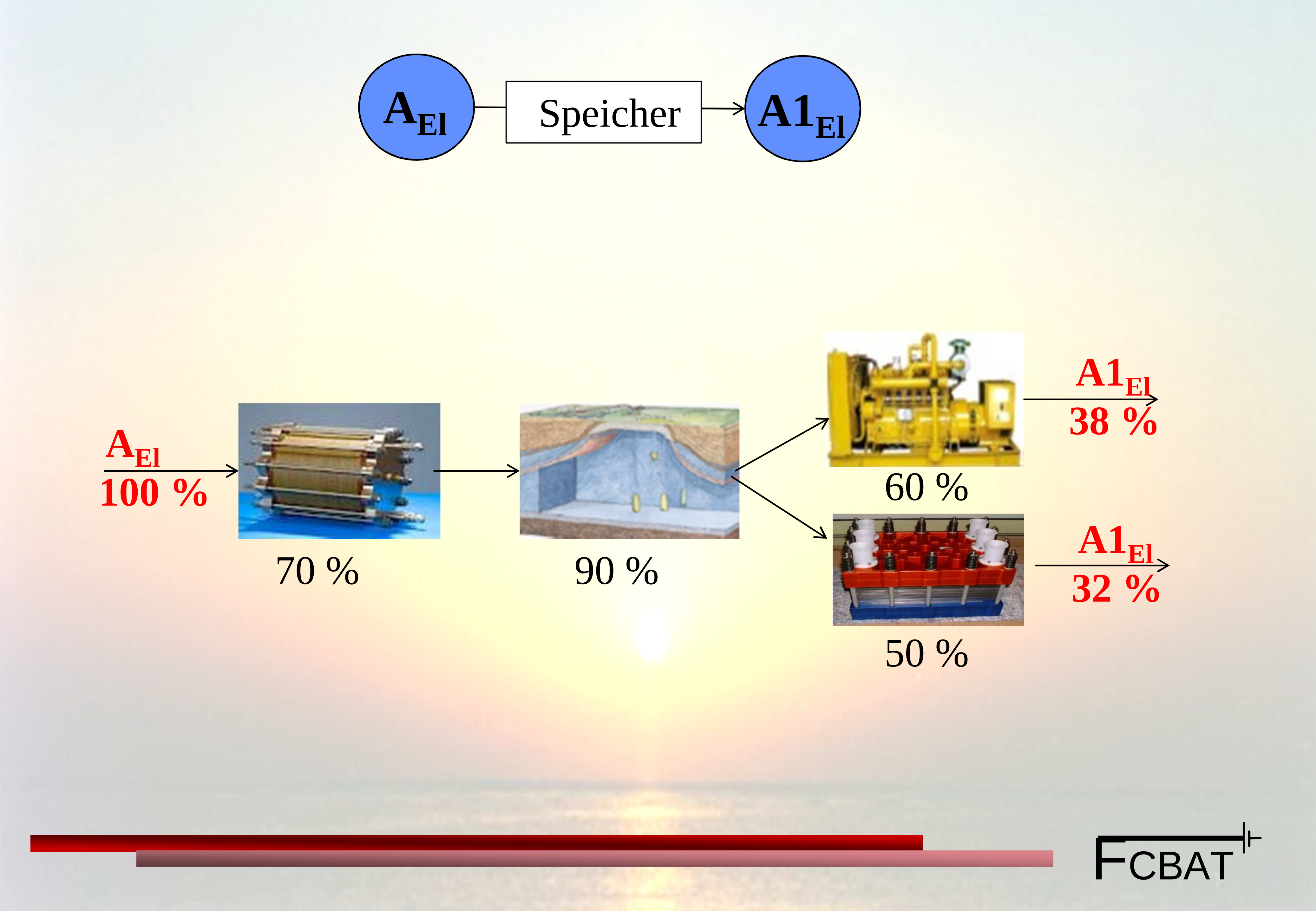


$\eta \approx 30 \ldots 40$ %

Voraussetzung:

- Salzkavernen

Source: Siemens, 2010



A_{El}
Speicher
$A1_{El}$
A_{El}
100 %
70 %
90 %
60 %
$A1_{El}$
38 %
50 %
$A1_{El}$
32 %
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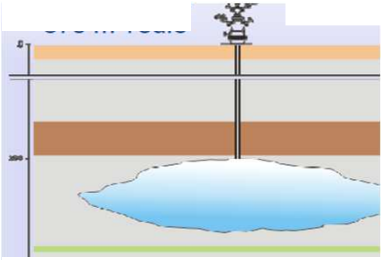
Centralized Storage Power Stations

- For economic operation typically only large units necessary
- Mainly located at special location (e.g. compressed air, pumped hydro)



Compressed H2

η ≈ 30…40 %

salt caverns

Pumped hydro

η ≈ 80 %

topographic sites

compressed air

η ≈ 50 % (*70 % ACAES*)

salt caverns

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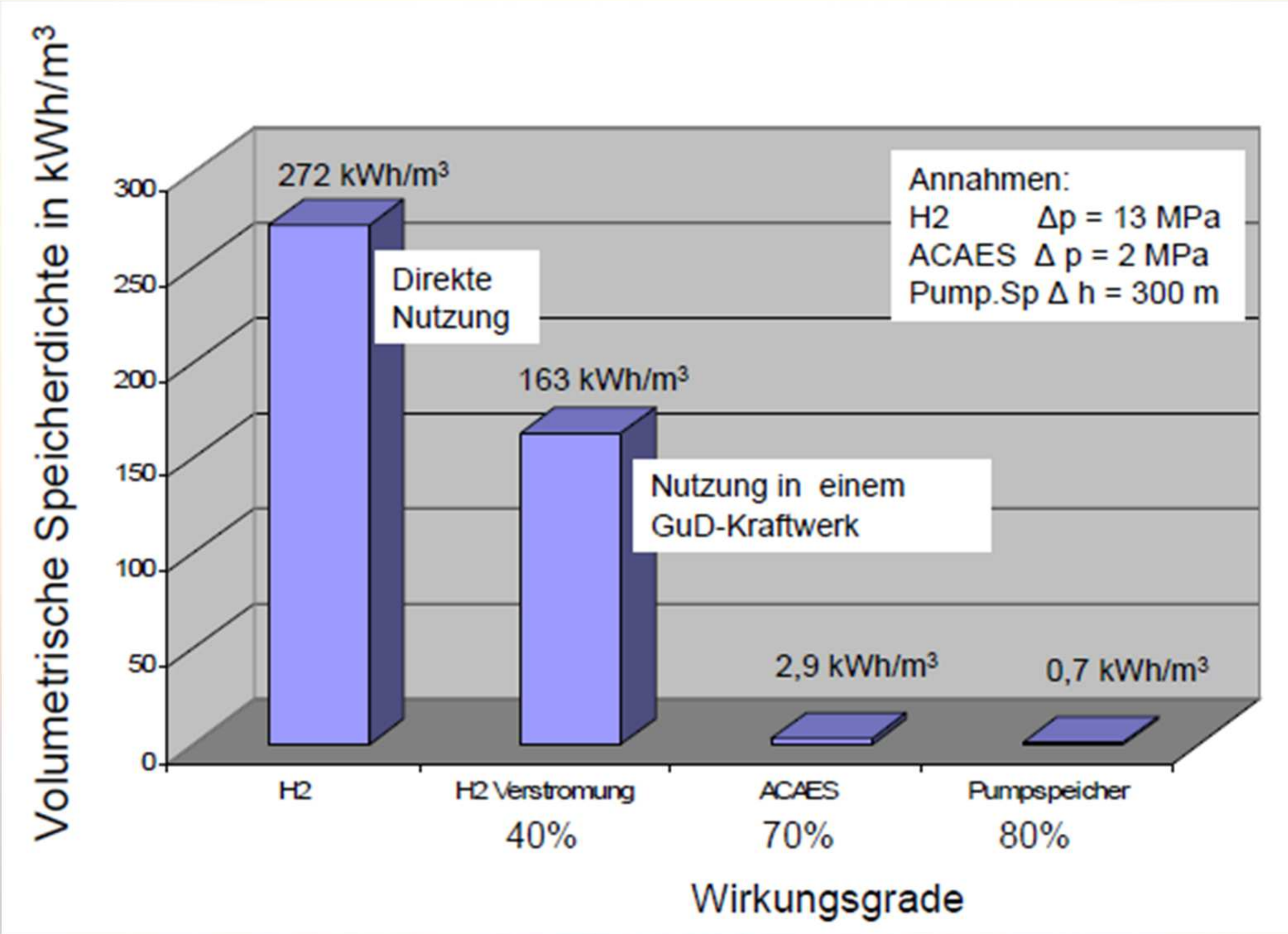
Speicherdichte ist entscheidend



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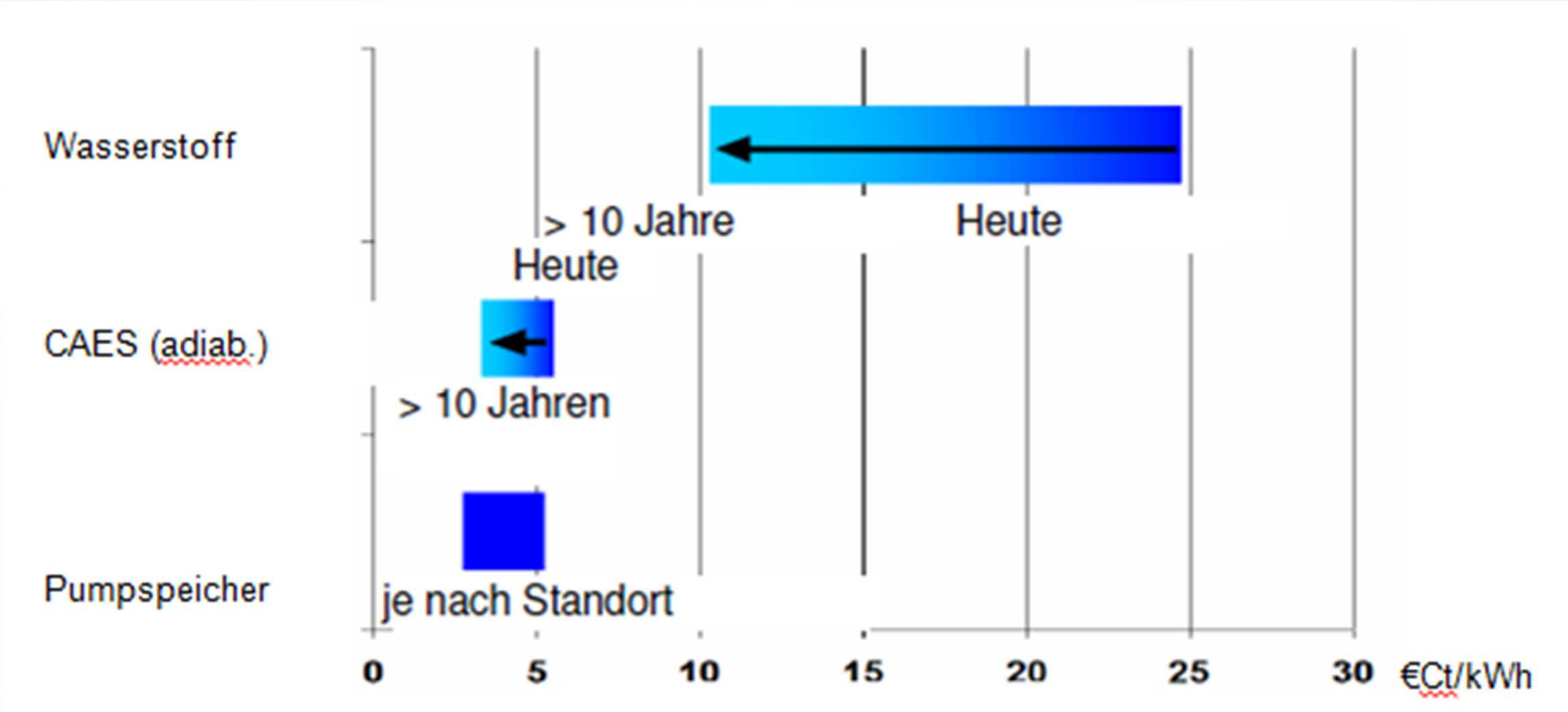
kWh-Kosten

Tagesspeicher (1 GW, 8 GWh, 1 Zyklus/d)



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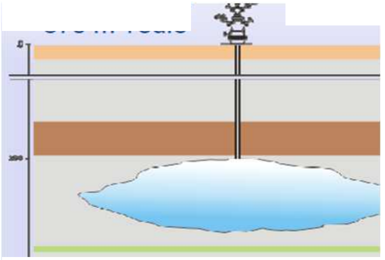
Centralized Storage Power Stations

- For economic operation typically only large units necessary
- Mainly located at special location (e.g. compressed air, pumped hydro)



Compressed H2

$\eta \approx 30 \ldots 40$ %

salt caverns

Pumped hydro

$\eta \approx 80$ %

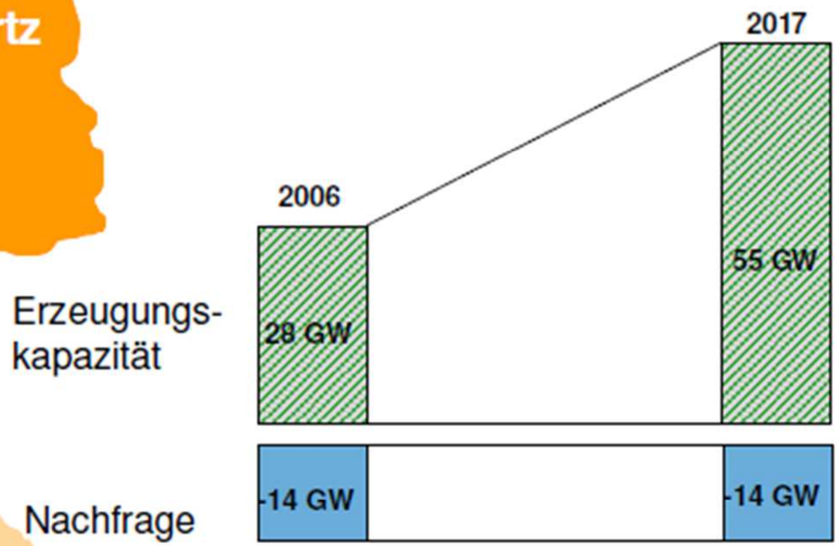
topographic sites

compressed air

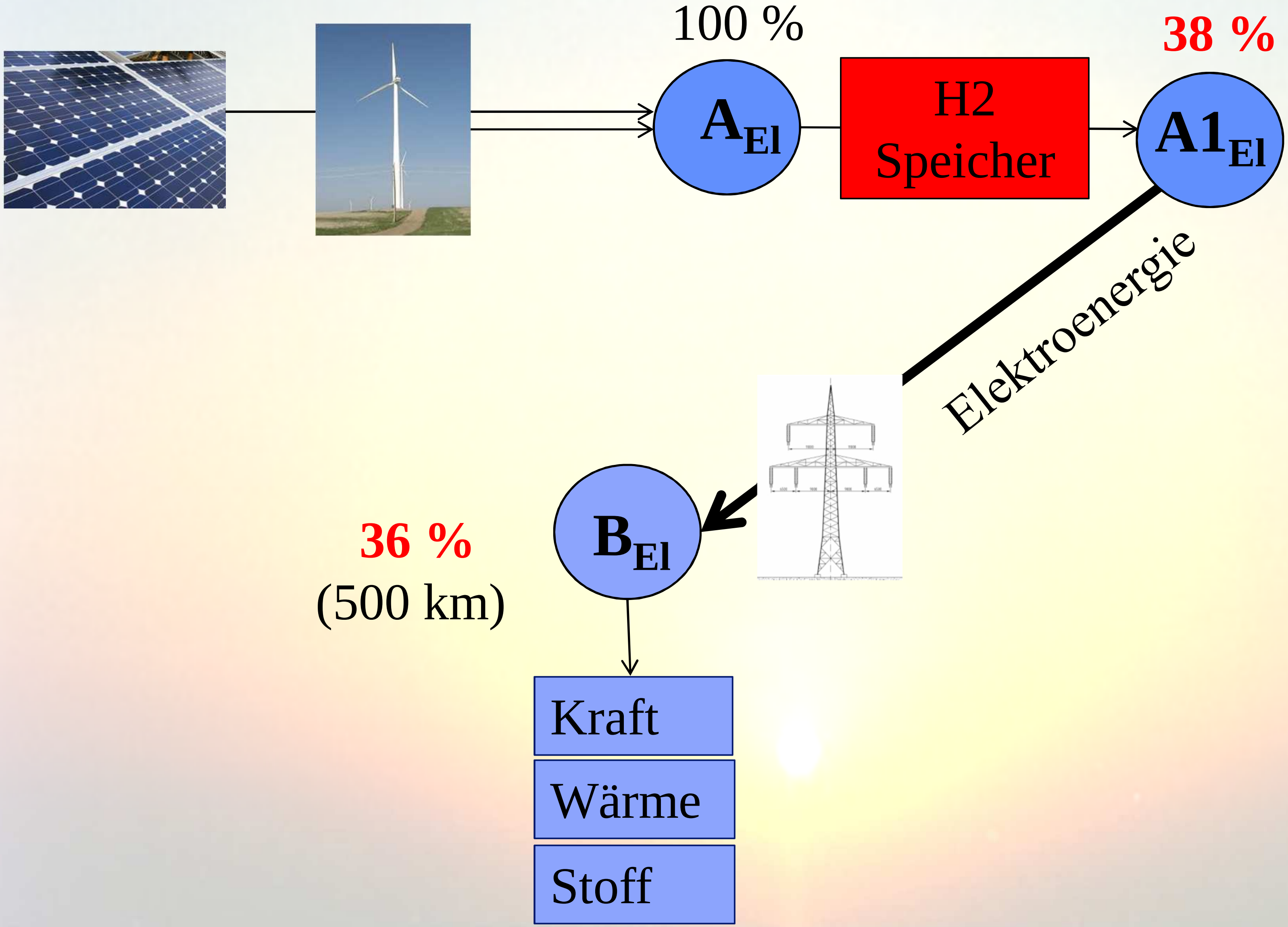
$\eta \approx 50$ % (*70 % ACAES*)

salt caverns

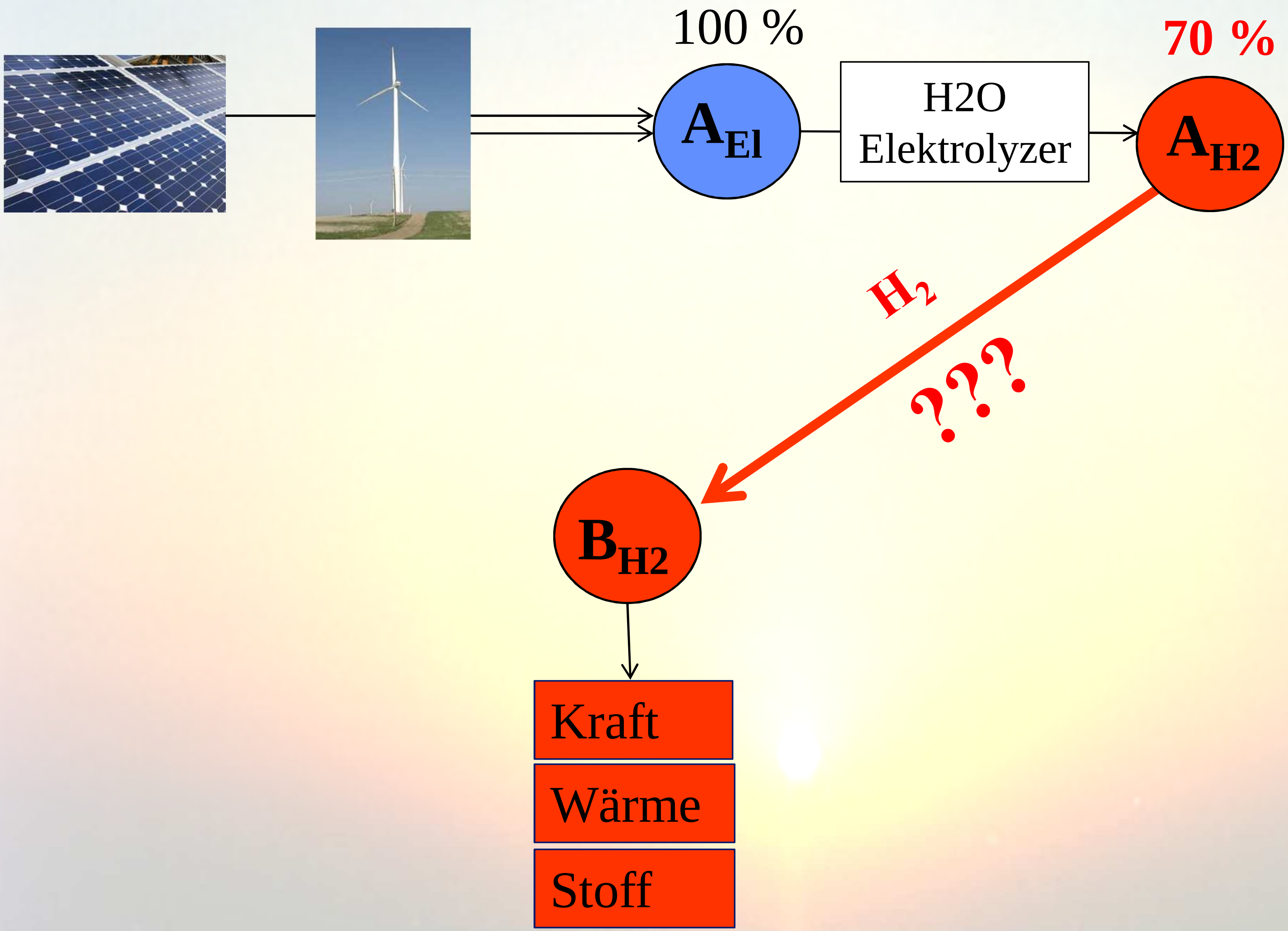
Erzeugung und Last in der 50Hertz Transmission Gebiet



- Bereits heute gibt es, im Vergleich zum Bedarf, in einigen Bereichen einen deutlichen Überschuss der Stromerzeugung
- Aber: Der Bau neuer Stromleitungen ist sehr zeitaufwändig


100 %
A El
H2
Speicher
38 %
A1 El
Elektroenergie
B El
36 %
(500 km)
Kraft
Wärme
Stoff

FCBAT



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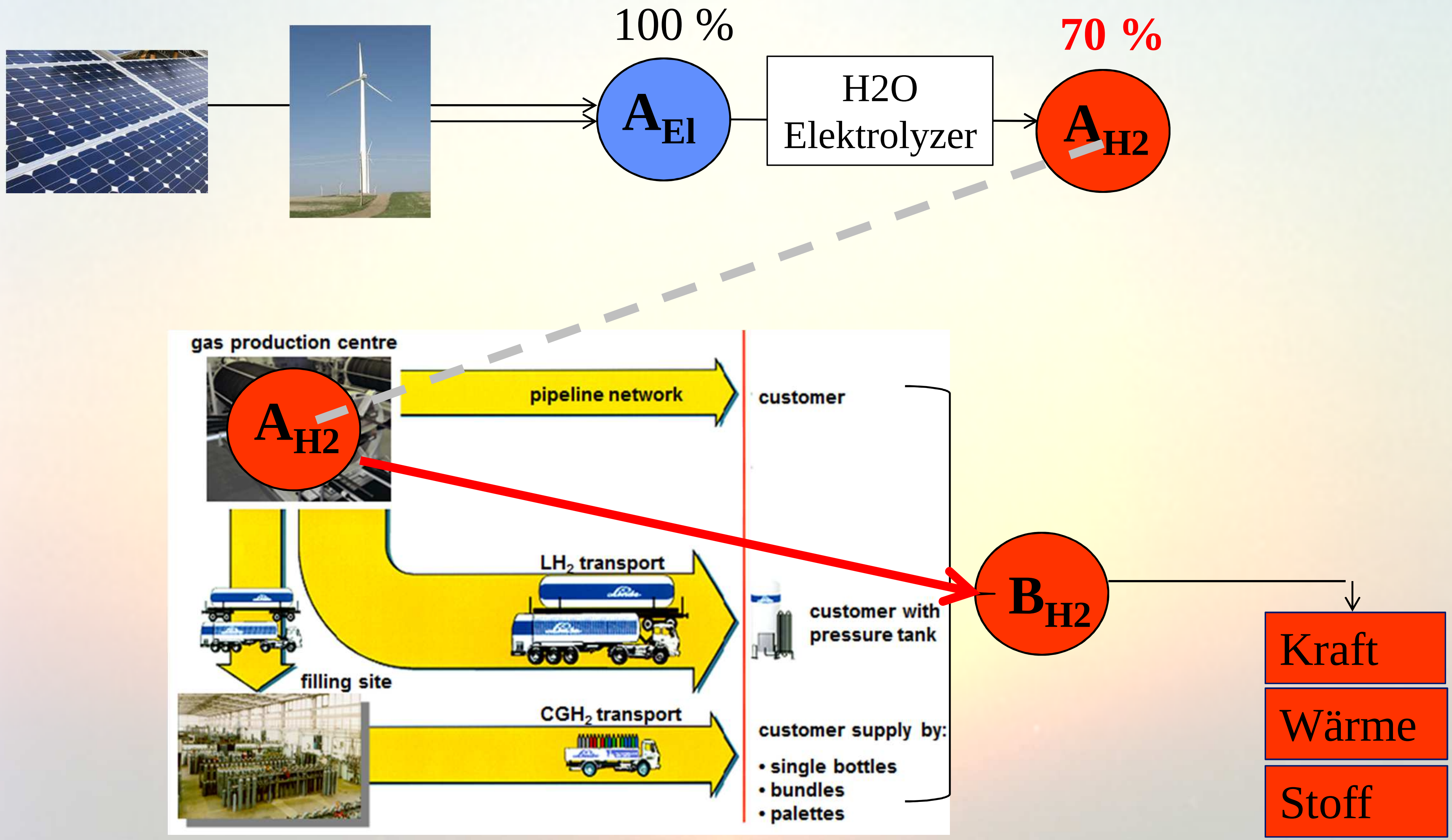

100 %
A_{El}
H2O
Elektrolyzer
70 %
A_{H2}
gas production centre
A_{H2}
pipeline network
customer
LH_2 transport
customer with
pressure tank
filling site
CGH_2 transport
customer supply by:
• single bottles
• bundles
• palettes
B_{H2}
Kraft
Wärme
Stoff

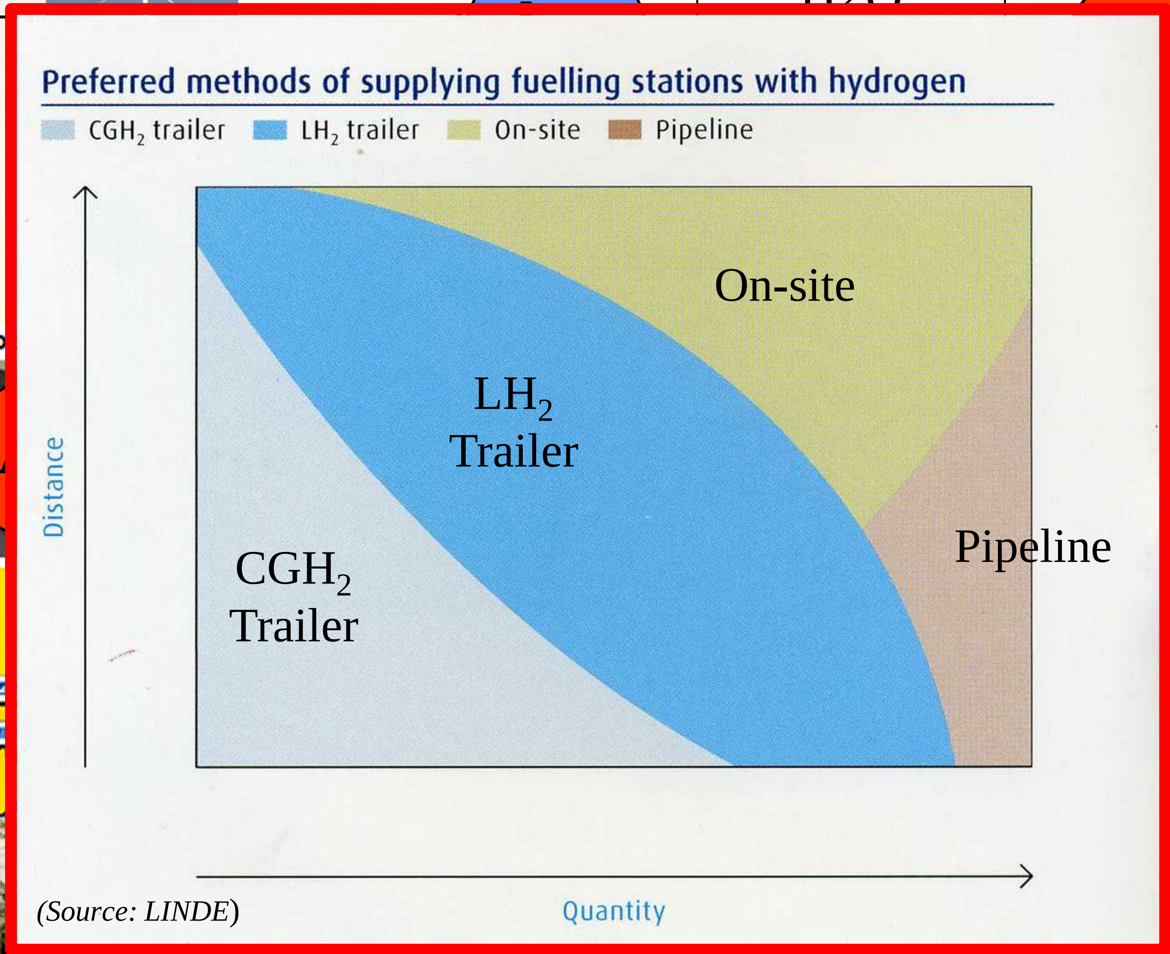
FCBAT

100 %

H_2O

70 %

H2



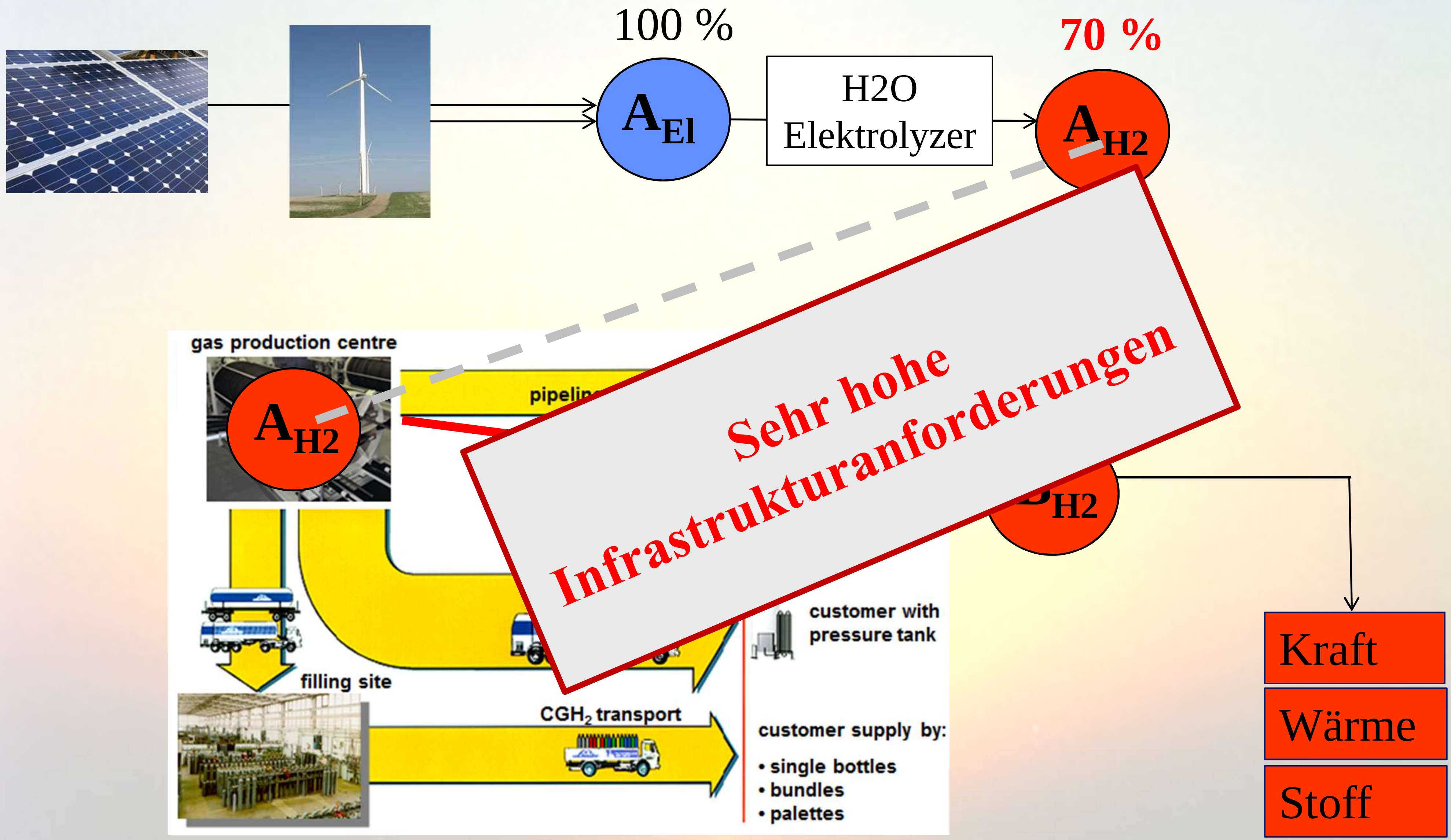
(Source: LINDE)

Kraft

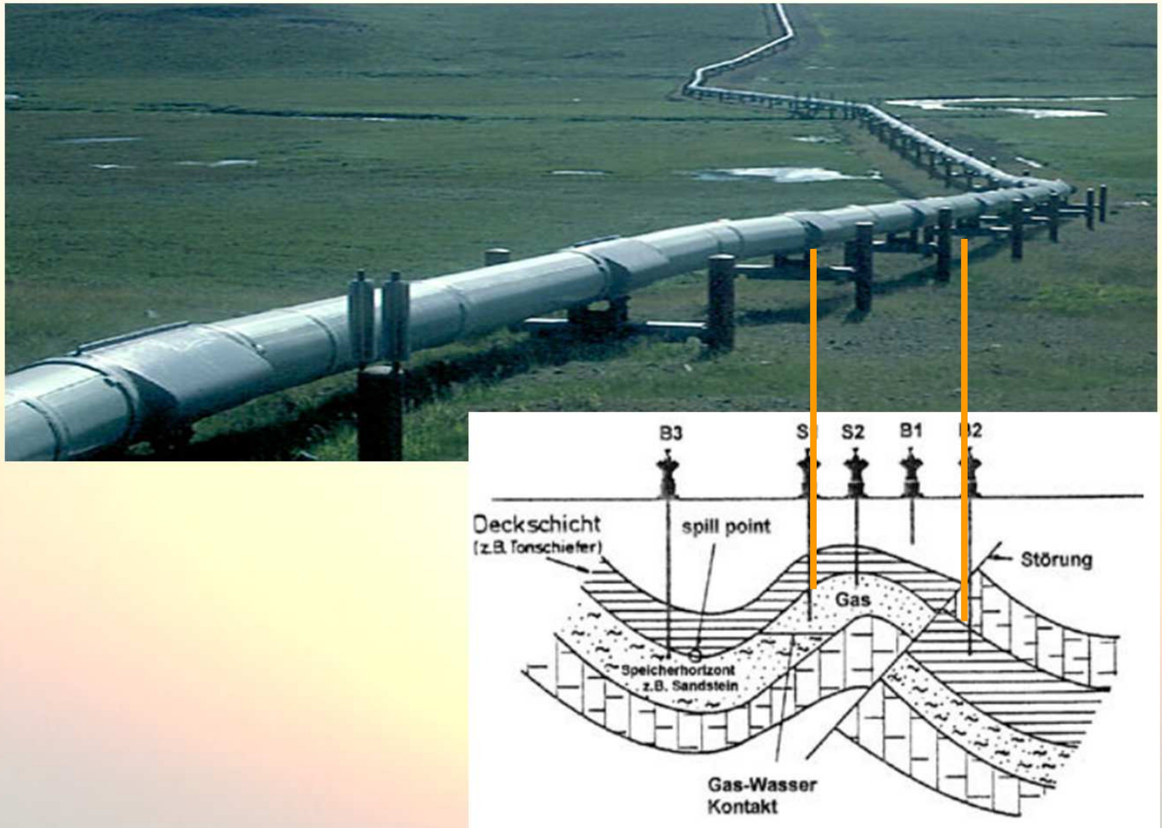
Wärme

Stoff

FCBAT


100 %
A_{El}
H2O
Elektrolyzer
70 %
A_{H2}
gas production centre
A_{H2}
Sehr hohe
Infrastrukturanforderungen
$H2$
customer with
pressure tank
filling site
CGH_2 transport
customer supply by:
• single bottles
• bundles
• palettes
Kraft
Wärme
Stoff

Erdgas-Infrastruktur nutzbar?



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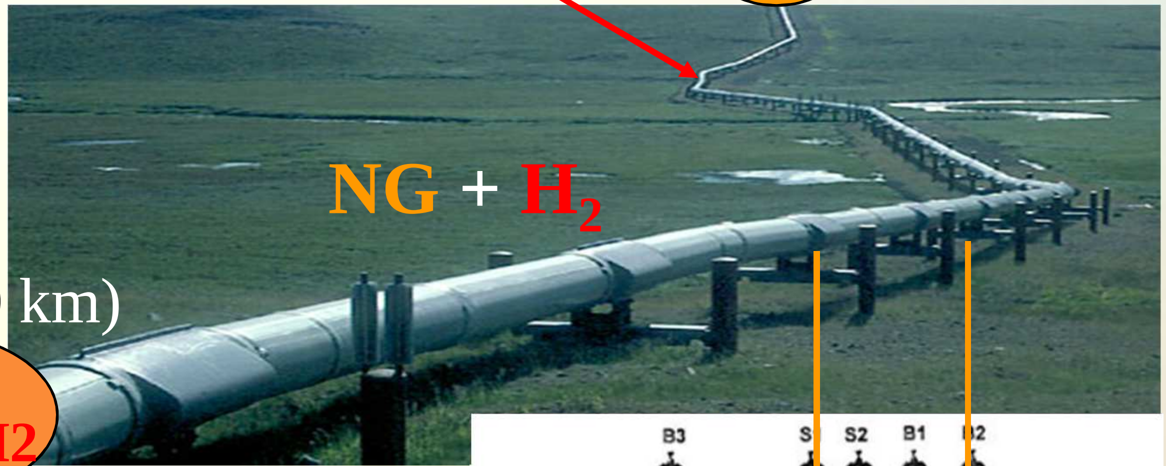
100 %

A_{El} — H2O Elektrolyzer → A_{H2}

70 %

H_2

A_{NG}



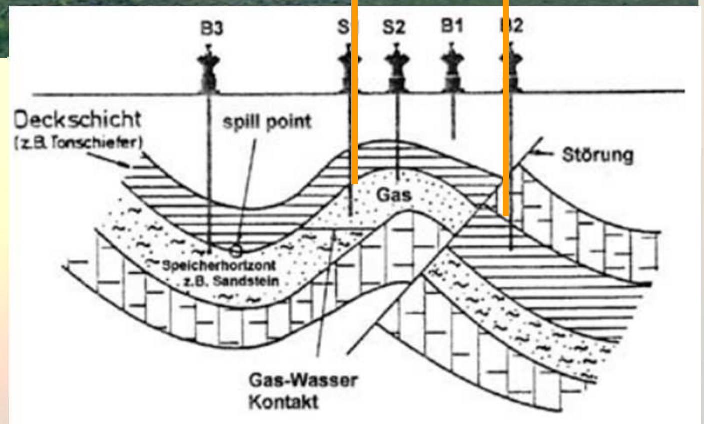
NG + H_2

Power to Gas (H2)

68 % (500 km)

$B_{NG + H2}$

- Kraft
- Wärme
- Stoff



100 %

A_{El}

H2O
Elektrolyzer

70 %

A_{H2}

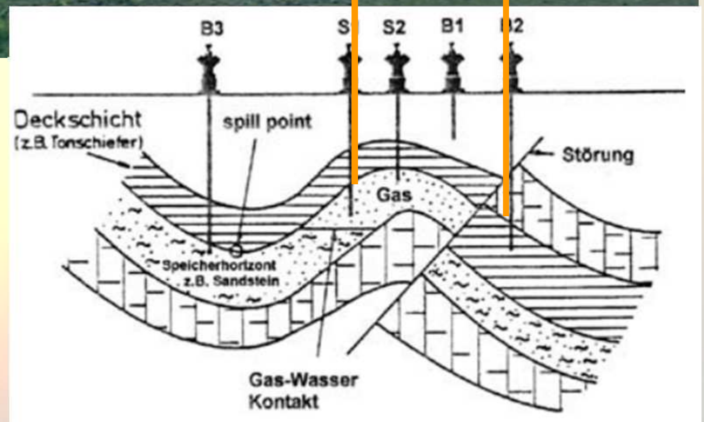
H_2

A_{NG}

Power to Gas (H2)

G(Gasgesetz) 262 bis zu 5 % H2

ca. 10 % in Vorbereitung



Kraft

Wärme

Stoff

100 %

A_{El}

H2O
Elektrolyzer

70 %

A_{H2}

H_2

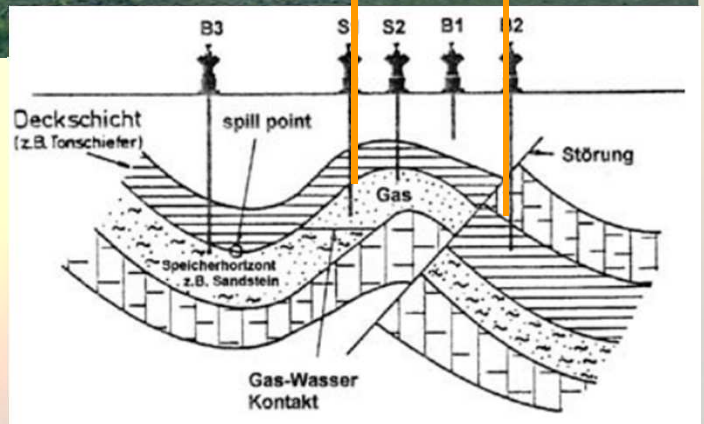
A_{NG}

NG + H_2

Power to Gas (H2)

G 262 bis zu 5 % H2
ca. 10 % in Vorbereitung

81,3 Mrd. m^3 NG/a in D
10 % => ca. 8 Mrd. m^3 H_2 /a
=> ca. **30 TWh H_2/a**



Stoff

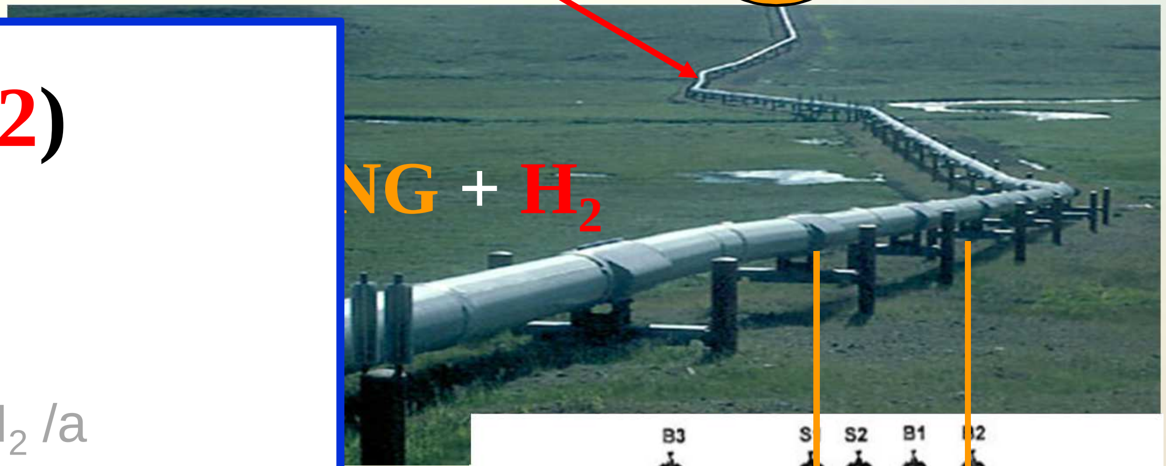
100 %

A_{El} → H2O Elektrolyzer → A_{H2}

70 %

H_2

A_{NG}



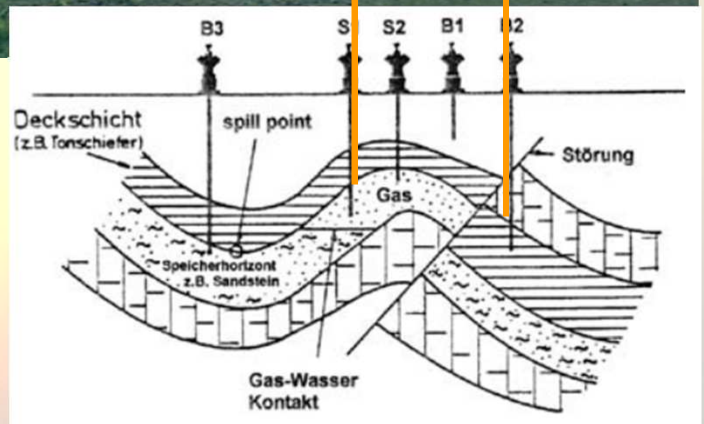
Power to Gas (H2)

G 262 bis zu 5 % H2
ca. 10 % in Vorbereitung

81,3 Mrd. m^3 NG/a in D
10 % => ca. 8 Mrd. m^3 H_2 /a
=> 30 TWh H_2/a

Strom in D: 510 TWh/a
1/3 ReGe: 170 TWh/a
=> Elektrolyse (66 %): **112 TWh H_2/a**

=> ca. 25 % der ReGen als H2 im Erdgasnetz speicherbar



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100 %

A_{El}

H2O Elektrolyzer

70 %

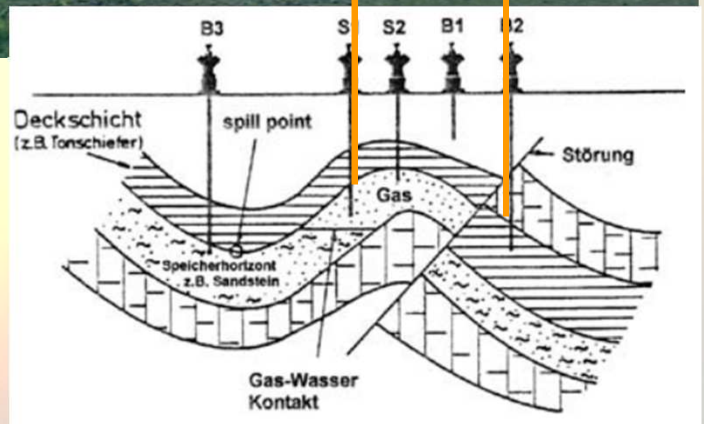
A_{H2}

H_2

A_{NG}

Power to Gas (H2)

≤ 25 % der ReGen als H2 im Erdgasnetz speicherbar



Kraft

Wärme

Stoff

100 %

A_{El} → H2O Elektrolyzer → A_{H2}

70 %

H_2

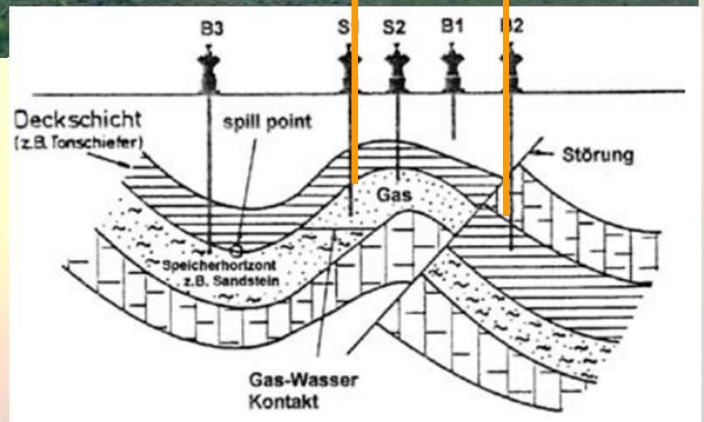
A_{NG}

Power to Gas (H2)

≤ 25 % der ReGen als H2 im Erdgasnetz speicherbar

Erdgasturbine	≤ 4 % H2
NG-ICE	≤ 2 % H2
Gasheizung	≤ 20 % H2

Anpassen!!!



100 %

A_{El}

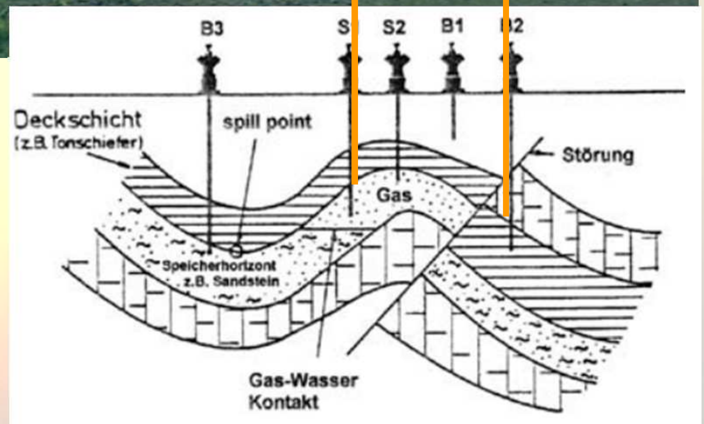
H2O
Elektrolyzer

70 %

A_{H2}

H_2

A_{NG}



Power to Gas

≥ 25 % der ReGen als H2 ???

Kraft

Wärme

Stoff

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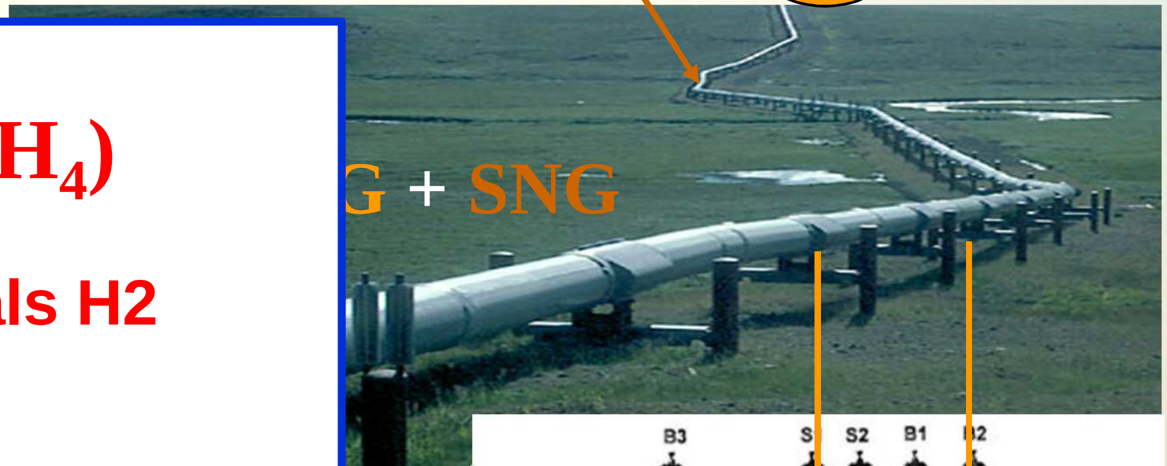
100 % A_{El} → H2O Elektrolyzer → 70 % A_{H2} → Methan-ization (CO_2) → 55 %* A_{SNG} A_{NG}



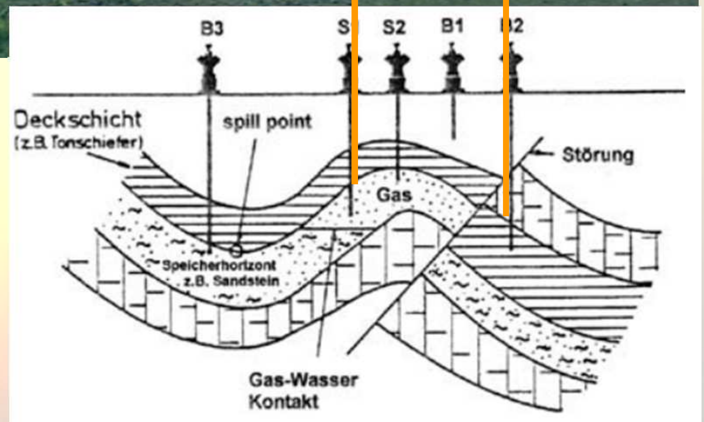
Po

G + SNG

≥ 25

im Er

speic



Power to Gas (CH_4)

≥ 25 % der ReGen als H2

Methanization

$$4H_2 + CO_2 \Rightarrow CH_4 + 2\,H_2O$$

$$\Delta H^o_r = -165\ \text{kJ mol}^{-1}$$

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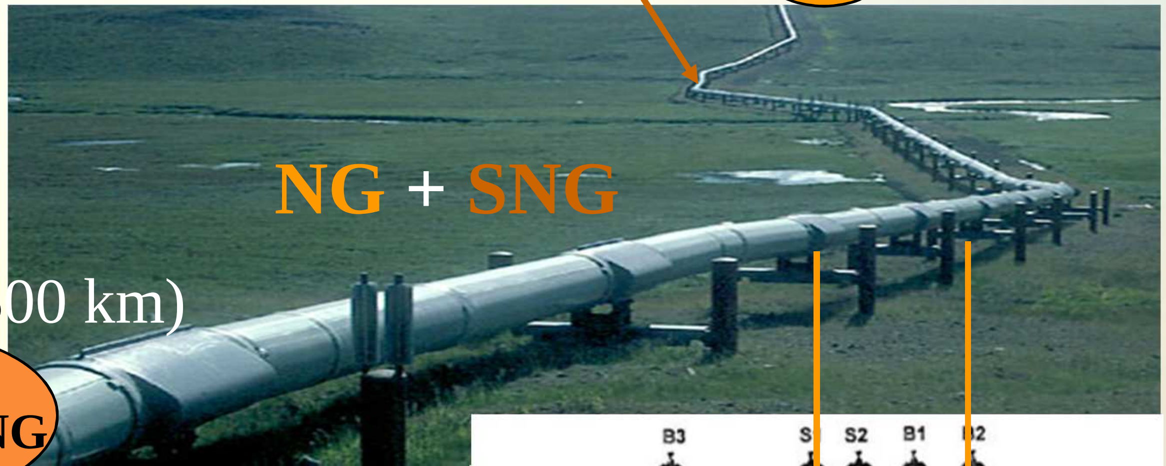
* abhängig von CO_2-Gewinnungsweg

100 %

A_{El} → H2O Elektrolyzer → 70 % A_{H2} → CO_2 → Metha-nization → 55 %* A_{SNG}

A_{NG}



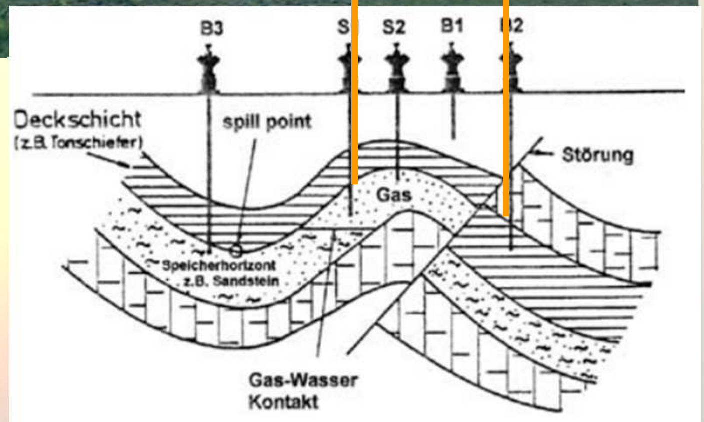
NG + SNG

Power to Gas (SNG)

53 % (500 km)

B_{NG+SNG}

- Kraft
- Wärme
- Stoff



≥ 25 % ReGe im Erdgasnetz als SNG speicherbar

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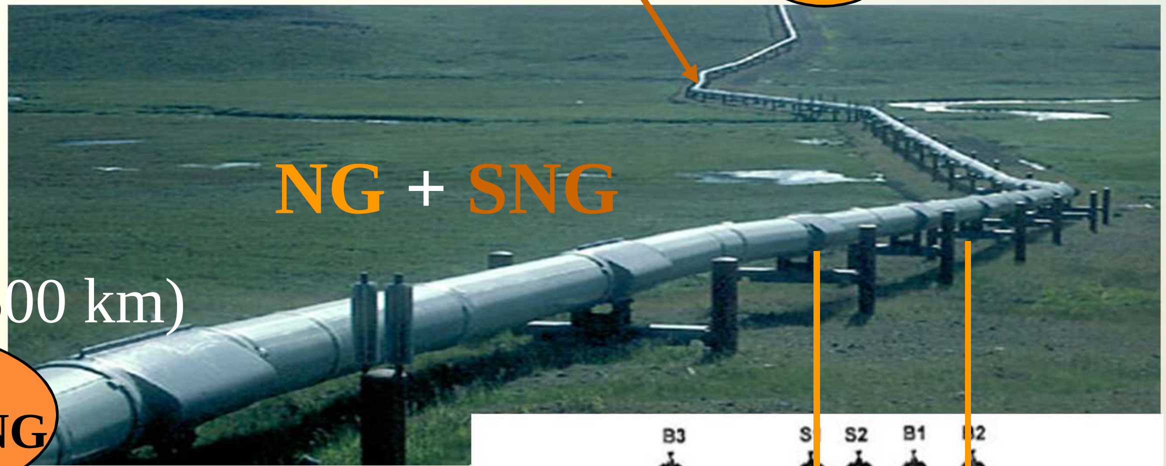
* abhängig von CO_2-Gewinnungsweg

100 %

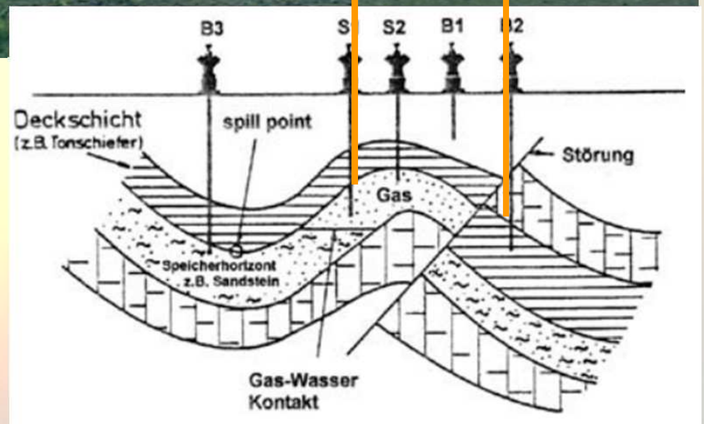
A_{El} → H2O Elektrolyzer → 70 % A_{H2} → (CO_2) Methan-ization → 55 %* A_{SNG}

A_{NG}

Power to Gas (SNG)



NG + SNG



53 % (500 km)

B_{NG+SNG}

wenn ≥ 25 % ReGe

- Kraft
- Wärme
- Stoff

Stoff → Erdgas-Reforming → B_{H2}

< 40 %

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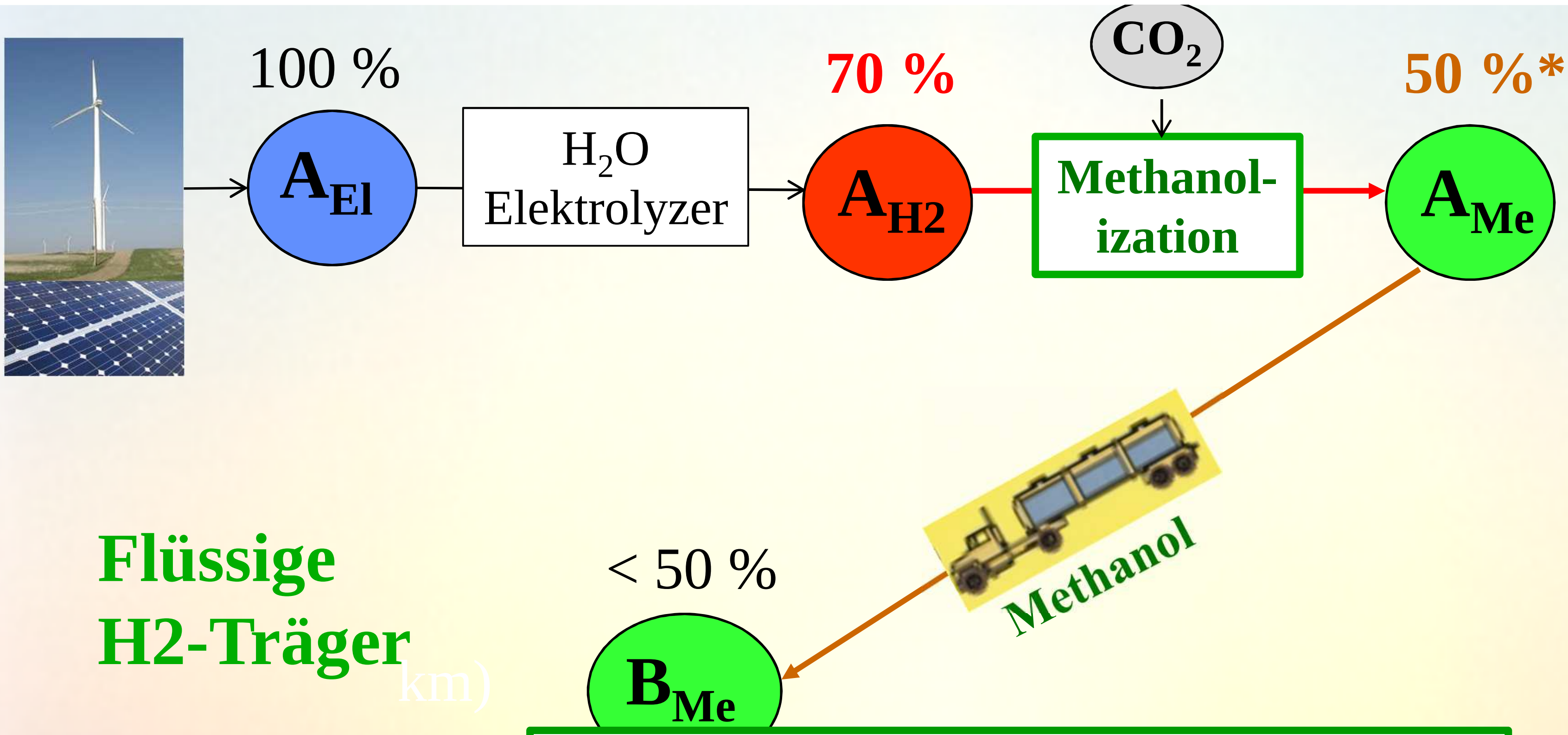
* abhängig von CO_2-Gewinnungsweg

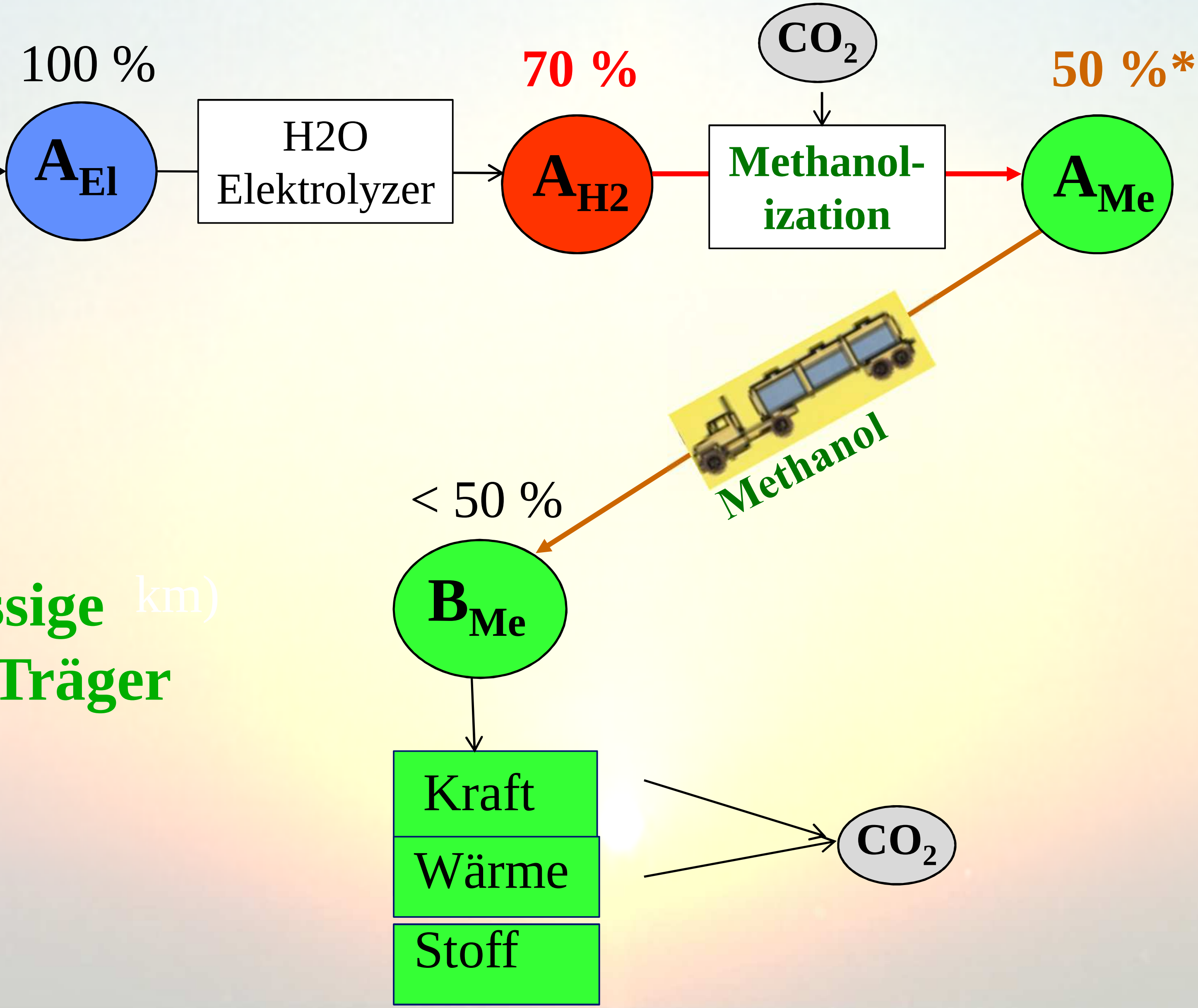


Flüssige H2-Träger

Methanolization

$$3H_2 + CO_2 \Rightarrow CH_3OH + H_2O$$

* abhängig von CO_2-Gewinnungsweg



Flüssige H2-Träger

* abhängig von CO_2-Gewinnungsweg

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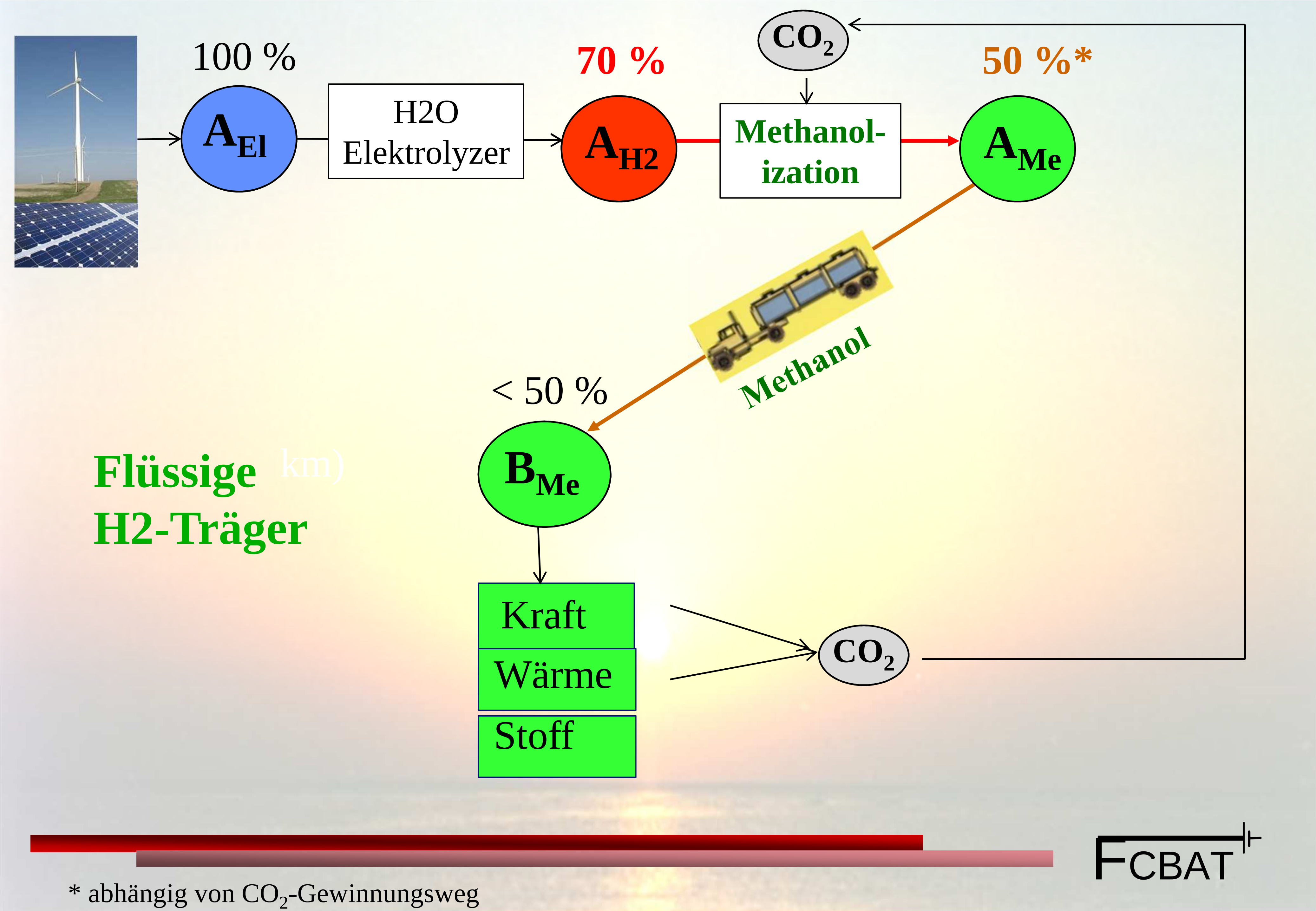
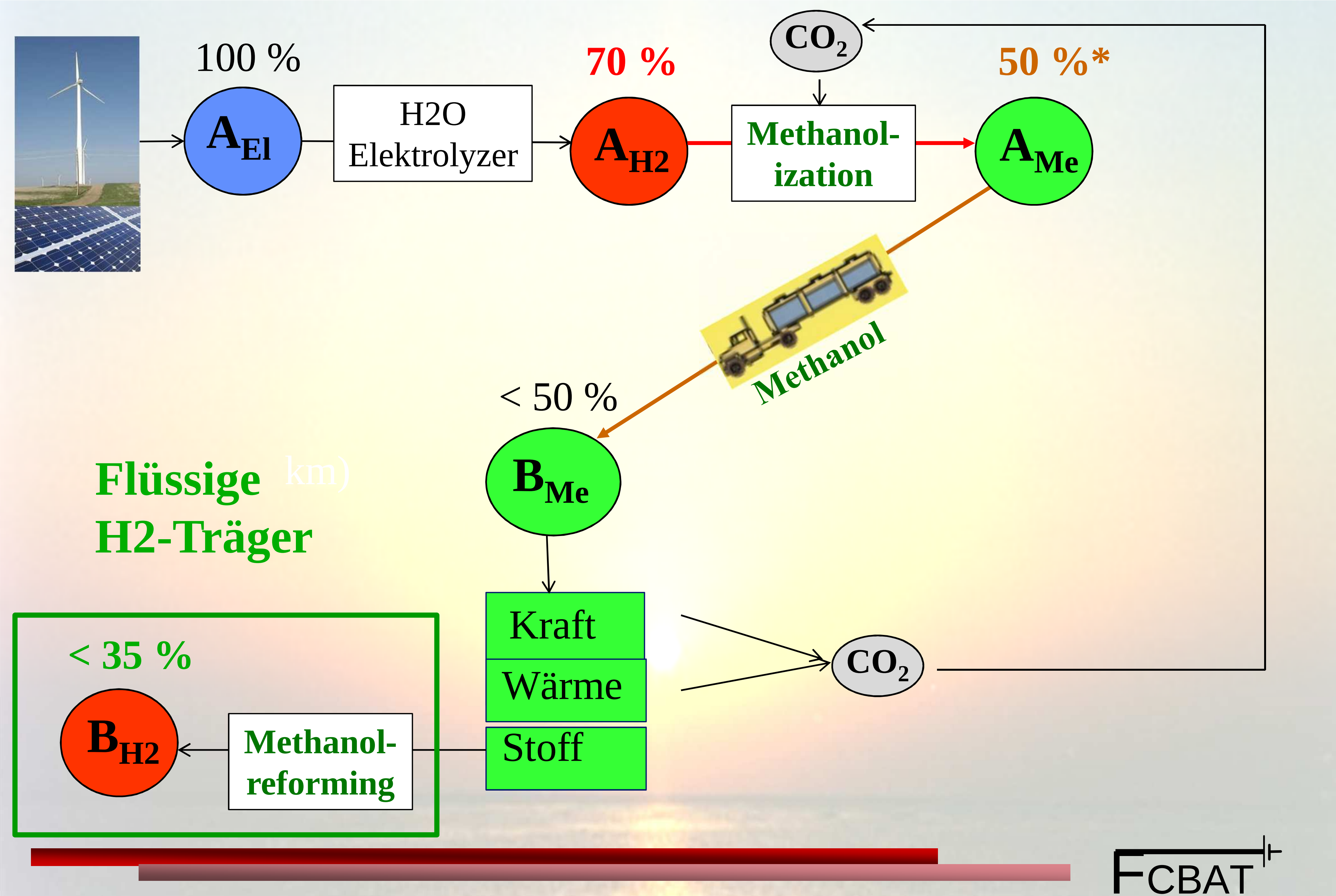
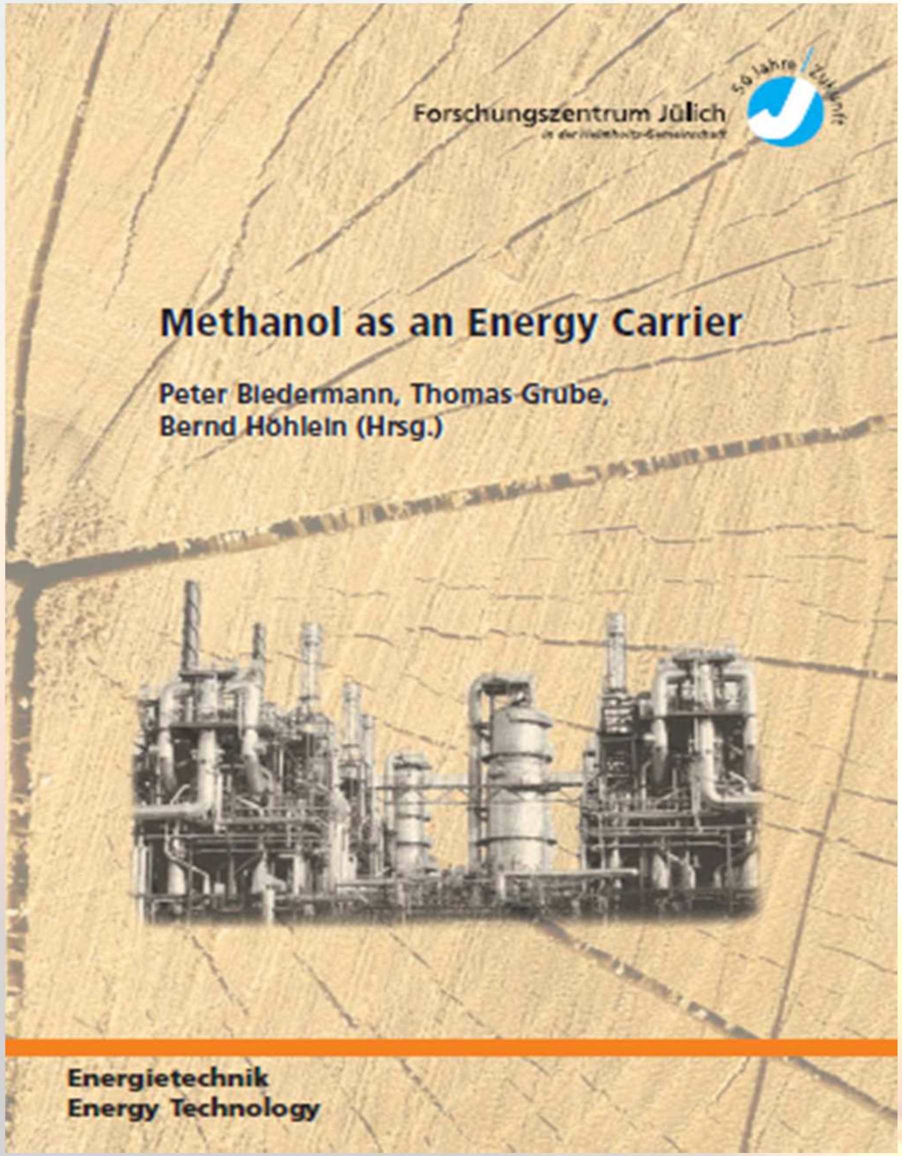

100 %
A El
H2O
Elektrolyzer
70 %
A H2
CO2
Methanol-
ization
50 %*
A Me
Methanol
< 50 %
B Me
Flüssige
km)
H2-Träger
Kraft
Wärme
Stoff
CO2
FCBAT
* abhängig von CO2-Gewinnungsweg

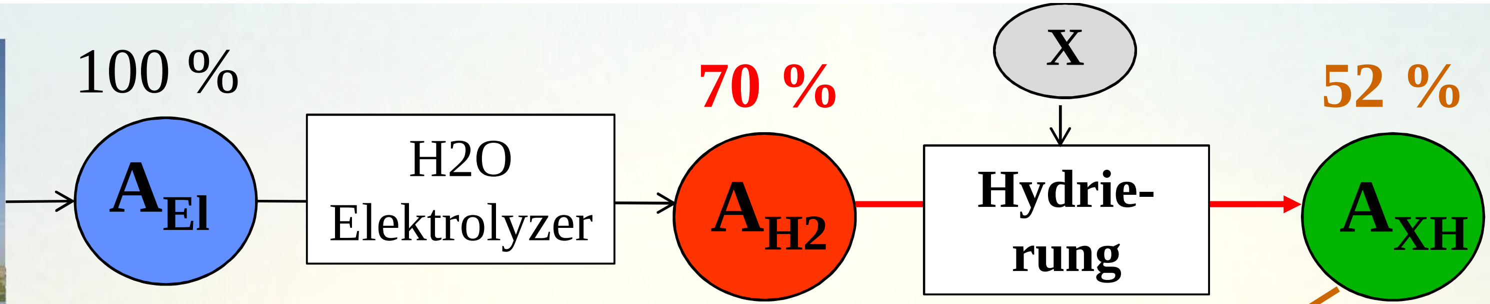


* abhängig von CO_2-Gewinnungsweg



Methanolwirtschaft

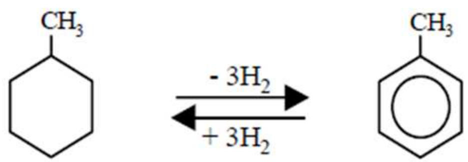
FCBAT



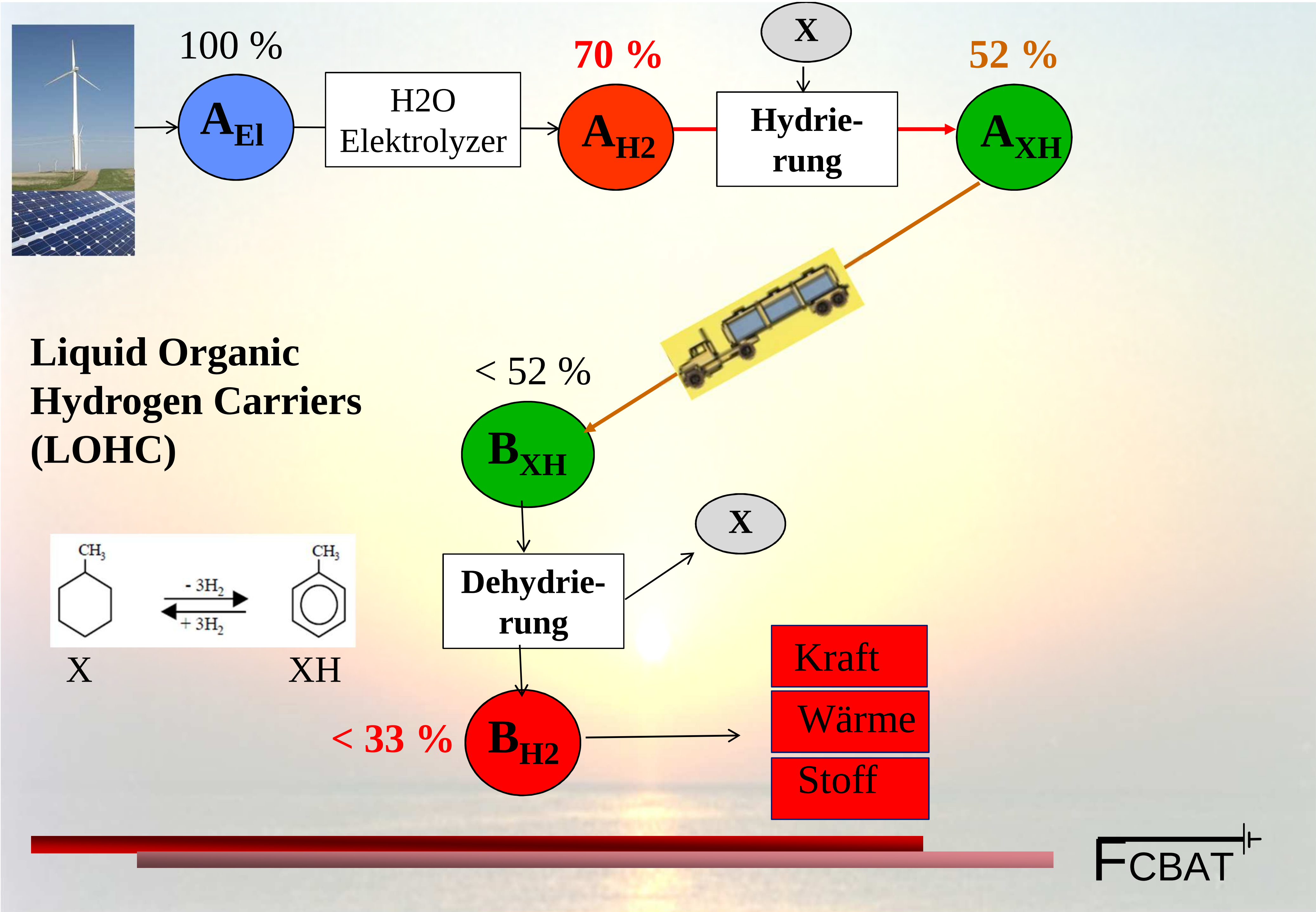
Liquid Organic Hydrogen Carriers (LOHC)

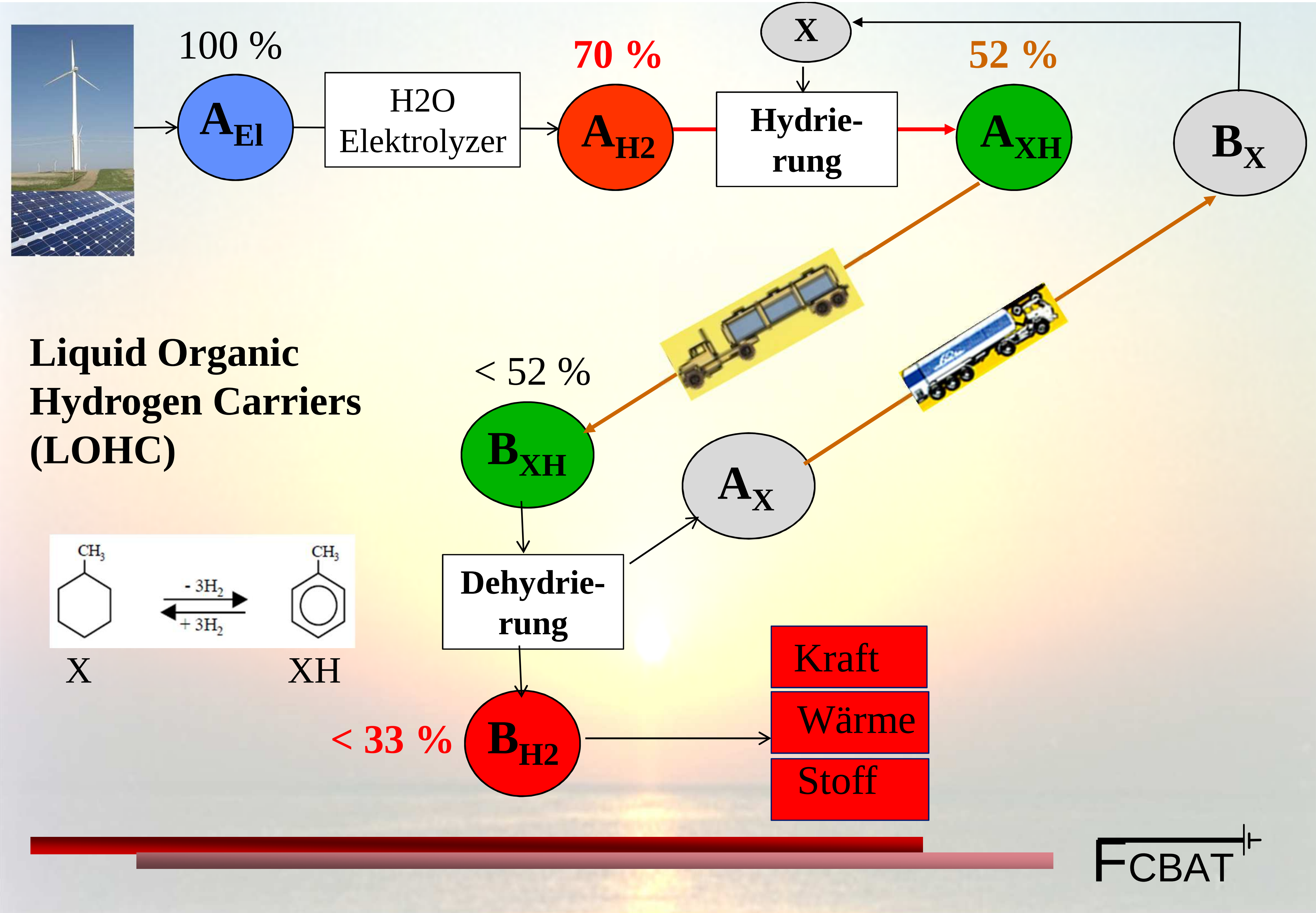
Liquid Organic Hydrogen Carriers (LOHC)

X + 1/2H2 ⇔ XH

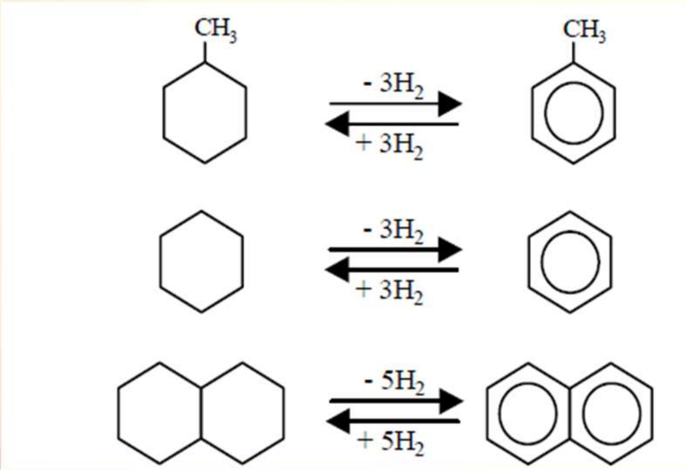


FCBAT


100 %
A_{El}
H2O
Elektrolyzer
70 %
A_{H2}
X
Hydrie-
rung
52 %
A_{XH}
Liquid Organic
Hydrogen Carriers
(LOHC)
< 52 %
B_{XH}
CH_3
$- 3H_2$
$+ 3H_2$
CH_3
X
XH
Dehydrie-
rung
X
Kraft
Wärme
Stoff
< 33 %
B_{H2}
FCBAT


100 %
A_{El}
H2O
Elektrolyzer
70 %
A_{H2}
X
Hydrie-
rung
52 %
A_{XH}
B_X
Liquid Organic
Hydrogen Carriers
(LOHC)
< 52 %
B_{XH}
A_X
CH_3
$- 3H_2$
$+ 3H_2$
CH_3
X
XH
Dehydrie-
rung
< 33 %
B_{H2}
Kraft
Wärme
Stoff
FCBAT

Liquid Organic Hydrogen Carriers (LOHC)



X XH

Methylcyclohexan ⇔ Toluol
6,1 Gew.-%

Cyclohexan ⇔ Benzol
7,1 Gew.-%

Decalin ⇔Naphten
7,2 Gew.-%

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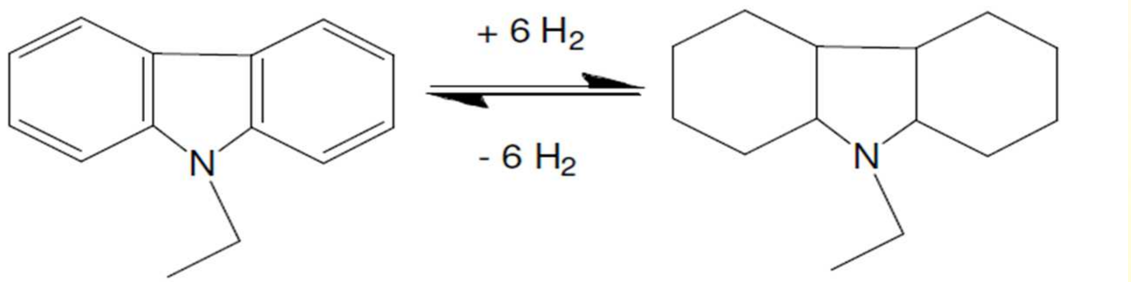
Liquid Organic Hydrogen Carriers (LOHC)

N-Ethylcarbazol Perhydro-N-ethylcarbazol



$C_{14}H_{13}N + 6H_2$ <==> $C_{14}H_{25}N$

X XH

5,7 Gew.-%
Hydrierung: 50 bar, 150 °C
Dehydrierung: ≈ 200 °C

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Zusammenfassung

FCBAT

95 %

B_{El}

100 %

A_{El}

KÖNIGSWEG !!!

95 %

B_{El}

38 %

36 %

H2 Speicher
El-H2-BZ

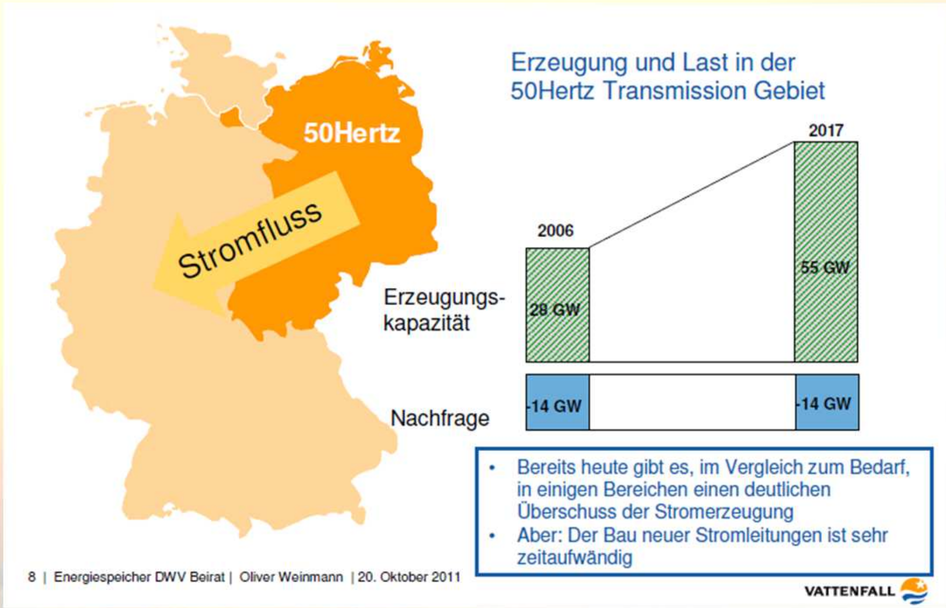
$A1_{El}$

B_{El}

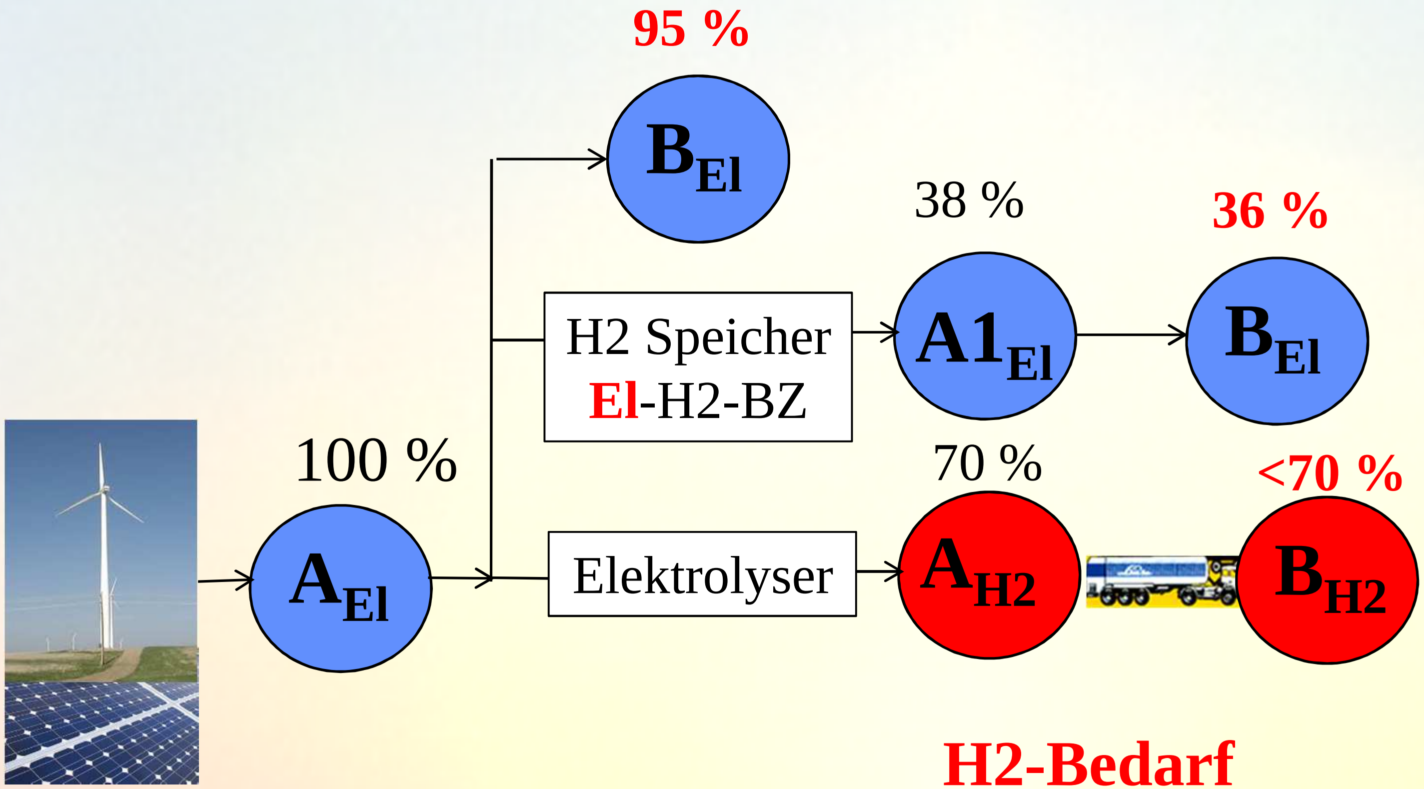
100 %

A_{El}

ReGe-Überschuss

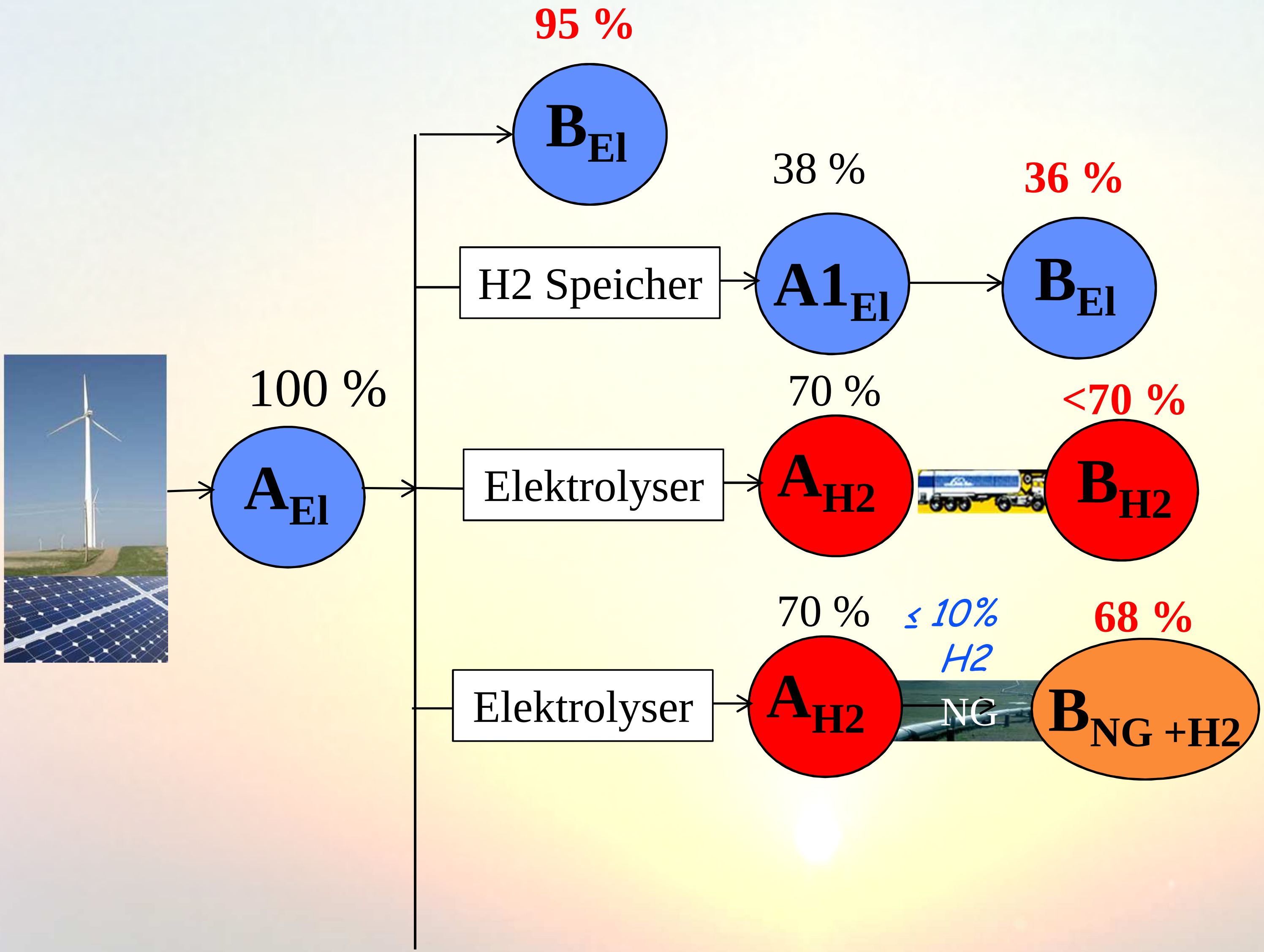


FCBAT


95 %
B_{El}
38 %
36 %
H2 Speicher
El-H2-BZ
$A1_{El}$
B_{El}
100 %
A_{El}
70 %
<70 %
Elektrolyser
A_{H2}
B_{H2}

H2-Bedarf


H2 für Verkehr
H2 Industrielle Nutzung
Wärmemarkt

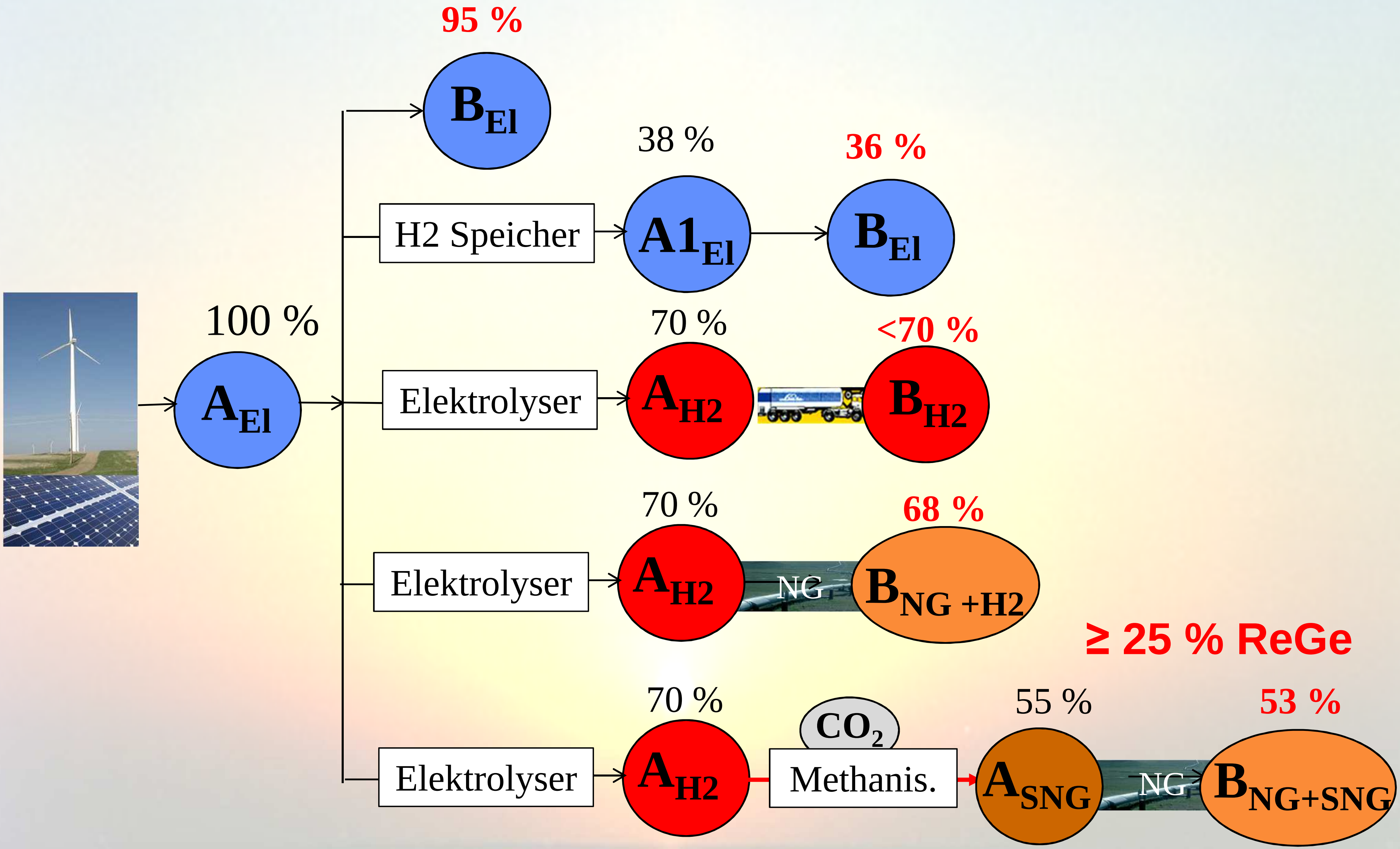


≤ 25 % ReGe

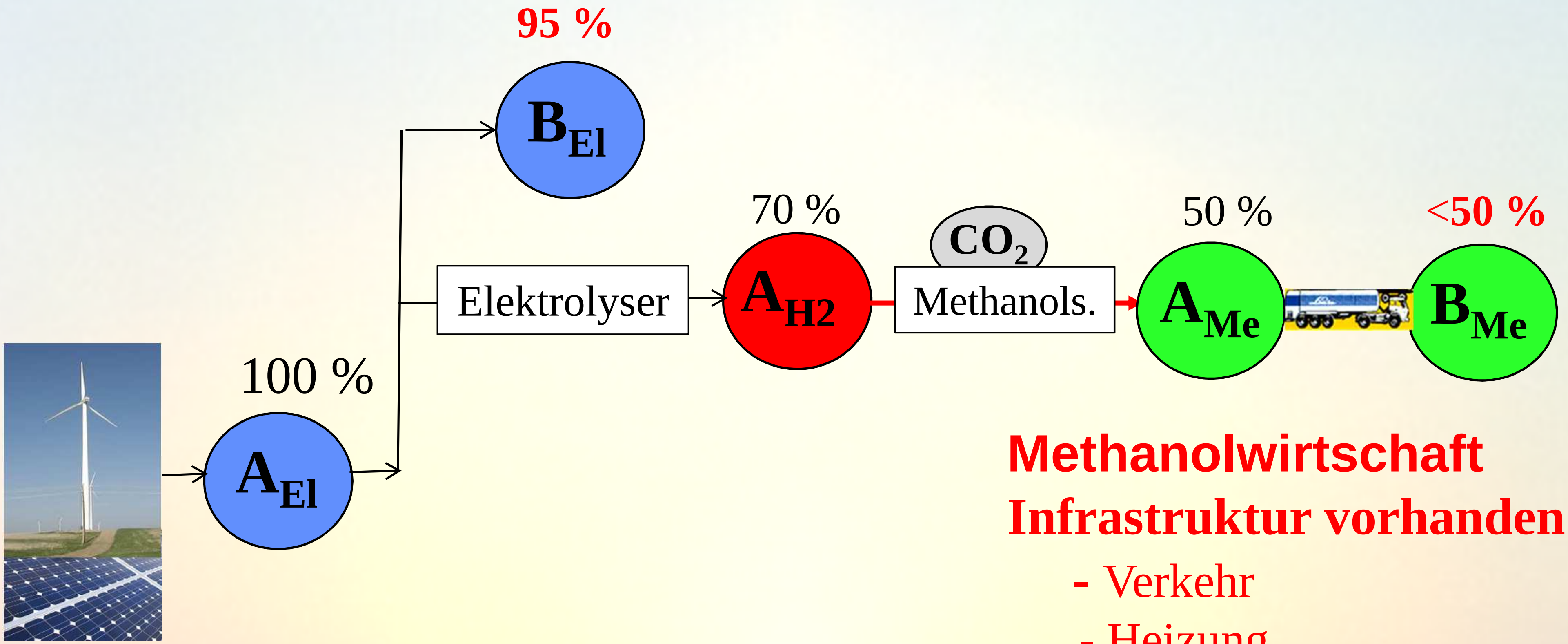
vorhandene Infrastruktur, NG-Bedarf

- Verkehr
- Heizung
- Industrie

FCBAT


95 %
B El
38 %
36 %
H2 Speicher
A1 El
B El
100 %
A El
70 %
<70 %
Elektrolyser
A H2
B H2
70 %
68 %
Elektrolyser
A H2
NG
B NG +H2
≥ 25 % ReGe
70 %
55 %
53 %
CO2
Elektrolyser
A H2
Methanis.
A SNG
NG
B NG+SNG

FCBAT

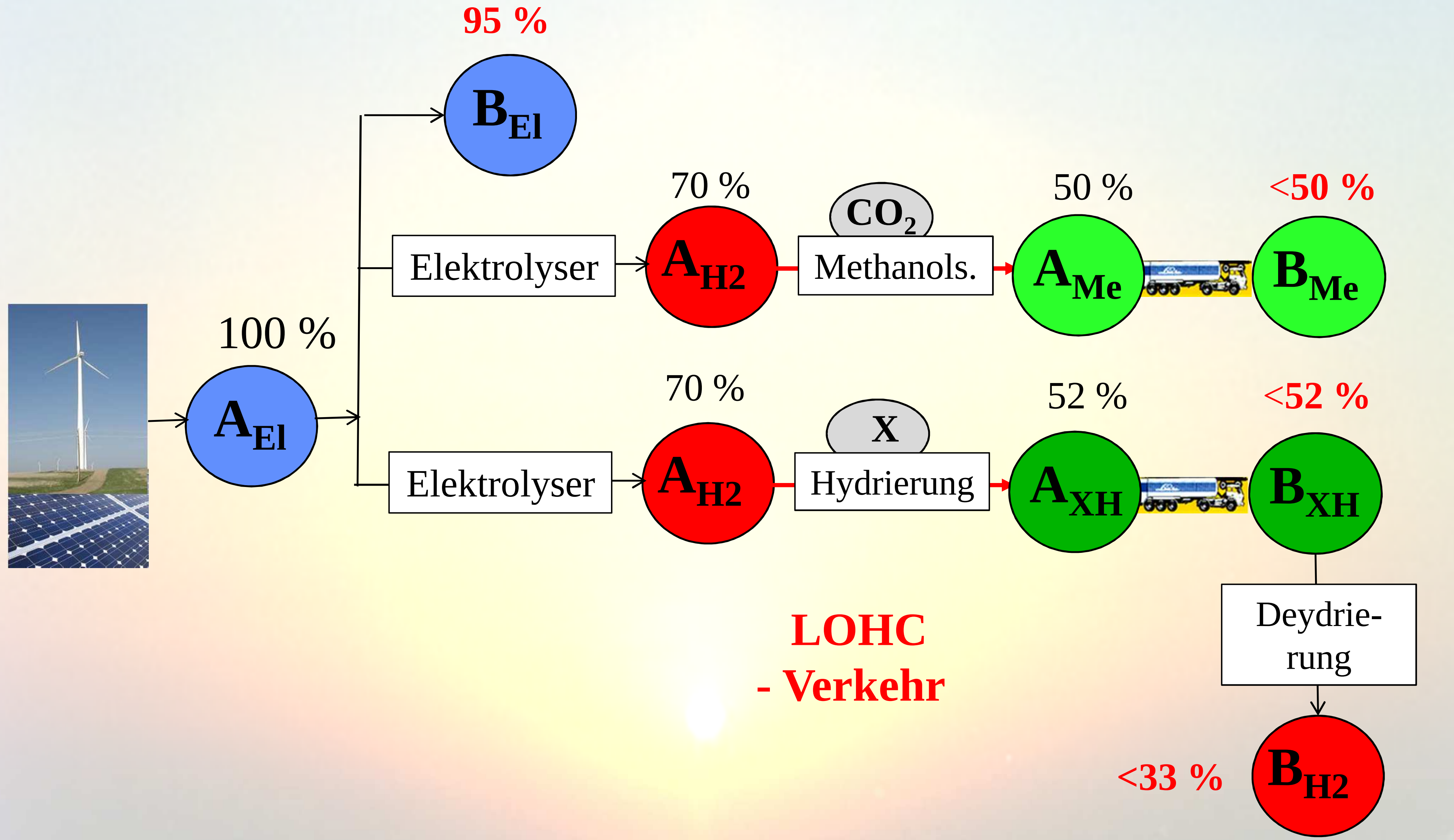


Methanolwirtschaft

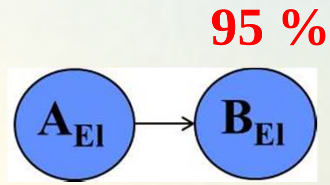
Infrastruktur vorhanden

- Verkehr
- Heizung
- Industrie

FCBAT


95 %
B_{El}
100 %
A_{El}
Elektrolyser
70 %
A_{H2}
CO_2
Methanols.
50 %
A_{Me}
<50 %
B_{Me}
Elektrolyser
70 %
A_{H2}
X
Hydrierung
52 %
A_{XH}
<52 %
B_{XH}
Deydrie-
rung
<33 %
B_{H2}
LOHC
- Verkehr

Zusammenfassung



1. Solange wie möglich Strom direkt verbrauchen

2. **Bei ReGe-Überschuss**, dann Elektroenergie:

   a - speichern über Wasserstoff
   b - wandeln in Wasserstoff, Transport und Nutzung als Endenergie
   c - wandeln in Wasserstoff => flüssige, chemische H2-Speicher für Transport und on-board Speicherung => Wasserstoff für Verkehr,
   d - Power-to-Gas zur Nutzung der NG-Infratruktur

3. a-d brauchen Elektrolyse
   => Elektrolyse wird Schlüsseltechnologie

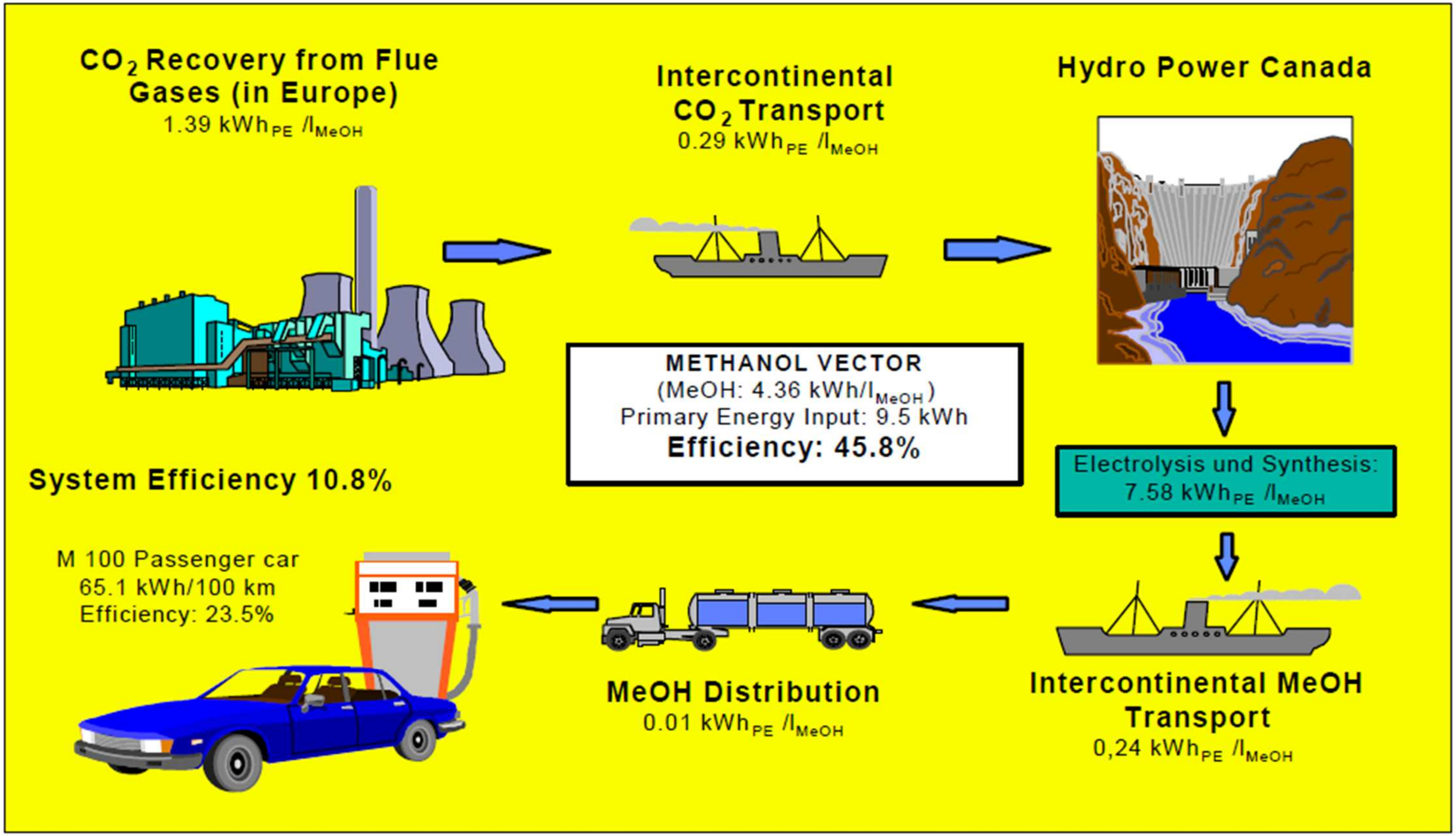
FCBAT

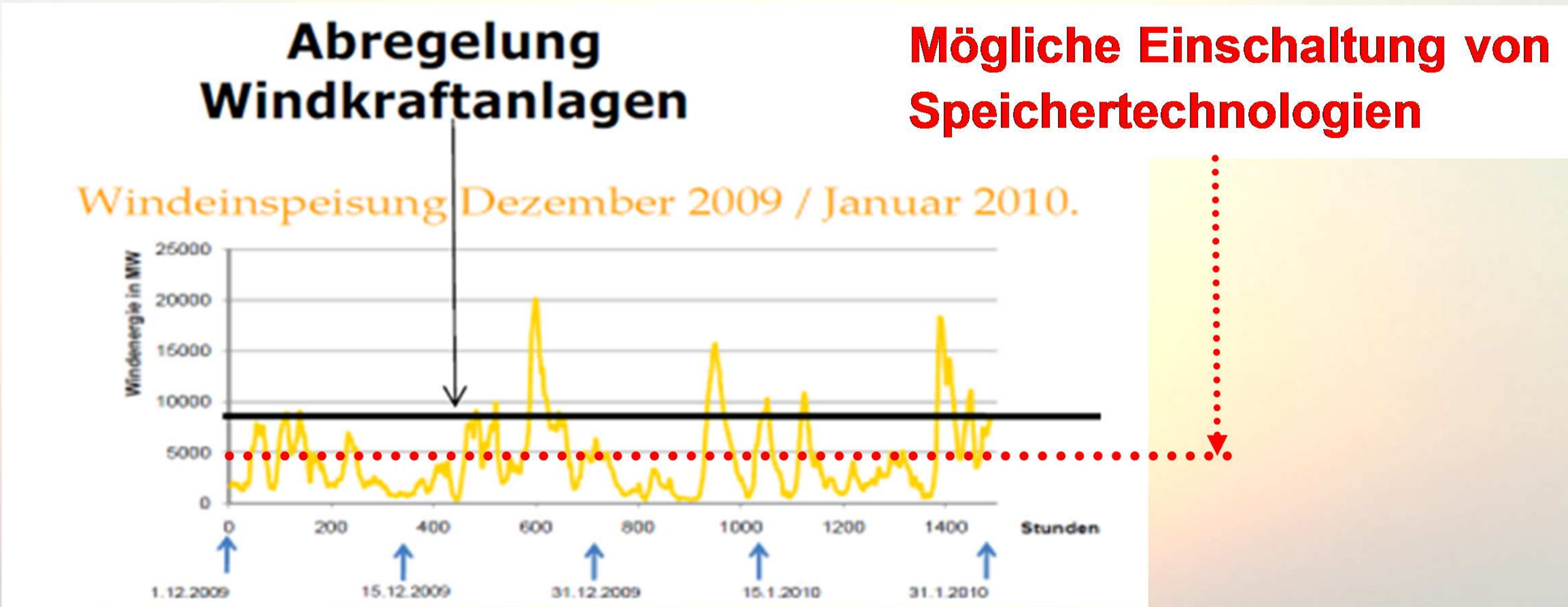
FCBAT

Speicherung regenerativer elektrischer Energien und die Vektorisierung von regenerativem Wasserstoff

Jürgen Garche

www.fcbat.eu


CO$_2$ Recovery from Flue Gases (in Europe)
1.39 kWh$_{PE}$ /l$_{MeOH}$
Intercontinental CO$_2$ Transport
0.29 kWh$_{PE}$ /l$_{MeOH}$
Hydro Power Canada
METHANOL VECTOR
(MeOH: 4.36 kWh/l$_{MeOH}$)
Primary Energy Input: 9.5 kWh
Efficiency: 45.8%
System Efficiency 10.8%
Electrolysis und Synthesis:
7.58 kWh$_{PE}$ /l$_{MeOH}$
M 100 Passenger car
65.1 kWh/100 km
Efficiency: 23.5%
MeOH Distribution
0.01 kWh$_{PE}$ /l$_{MeOH}$
Intercontinental MeOH Transport
0,24 kWh$_{PE}$ /l$_{MeOH}$



Abregelung
Windkraftanlagen
Mögliche Einschaltung von
Speichertechnologien
Windeinspeisung Dezember 2009 / Januar 2010.
Windenergie in MW
25000
20000
15000
10000
5000
0
0
200
400
600
800
1000
1200
1400
Stunden
1.12.2009
15.12.2009
31.12.2009
15.1.2010
31.1.2010

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